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DECISION ANALYSIS TECHNIQUE FOR PROGRAM EVALUATION (GOAL PROGRA--ETC(U)

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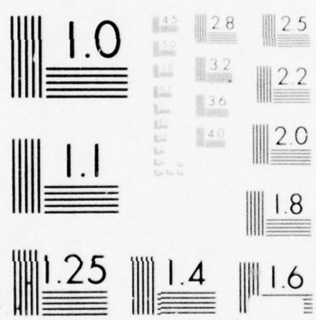

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DECISION ANALYSIS TECHNIQUE
FOR PROGRAM EVALUATION
(GOAL PROGRAMMING)

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Prepared by:

Thomas J. McGeehan

Defense Documentation Center
DDC-M (George Brundage, COTR)
Cameron Station
Alexandria, Virginia 22314

AAI
AUERBACH Associates, Inc.
121 North Broad Street
Philadelphia, Pennsylvania
19107

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A mathematical decision model for information service planning was derived from administrative goals. Program plans are assessed in the context of performance goals for six areas: available staff, available budget, program effectiveness, functional requirements, basic service requirements, investment programs to insure future progress.

The technique is an extension of linear programming that calculates optimal

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solutions to decision problems in the areas of resource allocation, policy analysis and program evaluation according to a set of preemptive priorities established by management.

The report includes a program in FORTRAN IV for computing solutions.

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SECTION I. INTRODUCTION AND SUMMARY

This draft Final Technical Report is a comprehensive presentation of AAI's study results from contract number DSA 900-75-5161. This effort has been directed towards the development of measures for quantifying the Defense Documentation Center's (DDC) operational goals.

1.1 PURPOSE AND BACKGROUND OF THE CONTRACTUAL EFFORT

This study builds upon the work of the DDC 10 Year Requirements and Planning Study completed in June 1976.[1] With that final report DDC was provided with a set of recommendations for projects that would serve its users' information requirements and which were technologically feasible in the planning period 1978 to 1988. The task remaining for DDC is to prepare budget programs over the next decade to deal with the long range requirements while at the same time meeting the administrative requirements of its top management.

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[1] For the detailed discussion of the prior study, see AUERBACH Associates, Inc. DDC 10 Year Requirements and Planning Study: Final Report, June 13, 1976. 2 Volumes. (AUER 2325/2326-TR-5; AD-A024 700, AD-024 701).

The usual technique for establishing an operating DDC budget follows the Program/Budget approval cycle of the Department of Defense. Program/Budgets are prepared at the operating level and with limited resources available to funding administrators a negotiation process is used to arrive at an operating Program/Budget.

This is an artful management process which has proven to be workable. The system, however, does not automatically provide solutions to dilemmas which develop in the negotiation process.

The tools of management science use data such as systems benefit projections, costs and user studies that go far in helping to make some of the difficult decisions in a rational manner. Indeed, such data are an important aspect of the current DDC Program/Budget. But data alone does not resolve decisions. Decision analysis techniques, usually based on a model of the decision environment, do provide a tool to answer questions about alternative program strategies and the value of various adjustments in resource allocations among projects. The use of models helps maintain a consistent basis for decision making from the operating level up through the administrative approval cycle.

The question which arose from the basic planning and requirement study is whether a more rigorous planning technique from the field of management science can help clarify the decision analysis process with regard to DDC's long range planning program. Specifically, can such a management tool help the DDC Administrator and his Program/Budget planners allocate resources and select programs that meet with the satisfaction of DDC's top management?

1.2 SUBJECT OF THE CONTRACTUAL EFFORT

Of the techniques available, mathematical modeling was identified as the most appropriate technique for the DDC environment. Furthermore, it is crucial that in order for the model to be practical, the decision analysis technique selected had to be capable of reflecting administrative judgement about the priority of desired goals and be able to deal with conflicting goals among several independent adminis-

trative constituencies served by DDC. The goal programming approach described by Lee[2] appeared to be the most practical technique for developing a model of a decision-making environment with multiple, competitive and conflicting goals and varying priorities.

Goal programming is a special extension of linear programming that has been developed for solving decision problems in which management sets goals which are achieved only at the expense of each other.

1.3 STUDY OBJECTIVE

It is the objective of this study to present a pragmatic goal programming model applicable to DDC's decision environment and test its application potential for resource allocation and project evaluation. The scope of the study is limited in that it does not attempt to include the full complexity of the DDC operation. Rather, the prime interest has been in developing a clear presentation of the goal programming methodology in the DDC environment.

1.4 SUMMARY OF THE STUDY METHOD

The study objective has been achieved in four steps:

1. First it was necessary to define a goal oriented program structure from an administrative point of view. This has been done through face-to-face interviews with top level administrators in the Department of Defense who were selected with DDC guidance to represent the administrative elements that DDC's program is intended to serve. The interview findings are shown in Appendix A. The interviews provided the basis for DDC's organizational goals as used in the goal programming model,

[2] Sang Lee, Goal Programming for Decision Analysis, AUERBACH Publishers, Inc. Philadelphia, Pa. 1972.

2. Second, an extensive literature search has been made to identify practical measures of information service useful for program evaluation. These results are provided in Section II.

3. The third step was to construct a goal programming model following the procedures outlined by Lee[3]:

   - define measureable input and output program elements for current and potential projects
   - Set target performance /criteria with DDC management participation
   - define operating relationships among current and potential projects

   The details of this task are shown in Section III.

4. Finally, the practical application potential of the technique has been examined in a simulated decision-making process using DDC's 1978 Program/Budget data. Section IV presents the test results and analysis, which were designed to examine and demonstrate:

   - the applicability of the technique for resource allocation problems
   - the applicability of the technique for program evaluation against operating constraints and organizational goals
   - the sensitivity of the model to changes in administrative priorities

1.5 SUMMARY OF RESULTS

1.5.1 General Study Results

The principal objective of the study has been to determine the application potential of the goal programming technique for DDC. In this regard, two conclusions have been reached:

- It appears certain that the technique can be applied usefully in a functioning information service environment such as DDC's. Procedures to demonstrate its use are provided in Section IV.
- The methodology appears to be generally applicable to other types of information service organizations, particularly those oriented toward program planning and budgeting. Consequently, the benefits of this effort could be extended beyond DDC.

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[3]Lee, Ibid.

1.5.2 Delivered Items

As a result of this study, DDC has been provided with the following:

- An objective method for program evaluation in which one of the principal benefits is a procedure to clarify and resolve apparent goal conflicts existing among various levels of management.
- A basic goal programming model specifically designed for use in evaluating DDC's program oriented plans in an organizational goal context.
- A FORTRAN program for solving goal programming problems, which have been installed and run on DDC's computer system (see Appendix D).
- Insight to the complexity of the agency's decision-making environment.
- Analysis of DDC's 1978 Program/Budget which was used as a source of data in this study.

1.5.3 Results of the Administrative Interviews

The interview findings (Appendix A) show a complex goal structure that makes up DDC's decision-making environment. In addition to its line management within the Defense Logistics Agency[4], DDC has independent constituencies in the Office of the Director, Defense Research and Engineering, as well as the Research, Development, Test and Evaluation Commands of the Army, Navy and Air Force.

Administrators within these agencies reflect conflicting goals with regard to the DoD scientific and technical information (S&TI) program. The conflicts are expressed not only between agencies, but often within the responses of individual administrators.

In comparison to the user need and technological goals derived from the 10 Year Requirements and Planning Study, the administrators'

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[4] The Defense Logistics Agency was formerly the Defense Supply Agency.

goals for the S&TI program differ primarily on the degree of systems improvement that should be achieved by the information program. Administrators are relatively satisfied with the limitations of the status quo, users and information professionals are not.

1.5.4 Results of the Model Building Effort

The results of this study demonstrate that goal programming supplements DDC's traditional decision making process in these key ways:

- It helps define the decision environment in unambiguous terms
- It provides systematic consideration of alternative decision strategies, often involving different levels of management
- It ensures that all key elements are considered each time a decision strategy is evaluated
- It creates a documented record of the decision process
- It provides quantitative solutions to management problems

In addition, goal programming's most interesting feature is that it helps decision makers establish priorities for proposed operating programs. Moreover, it encourages them to define goals that justify information products, services and projects. In this context the agency's output is clearly related to organizational purpose. Thus, the model provides a basis for information service decision making in which both information professionals and general managers at all levels within the organization can participate on an equal basis. Even though no perfect decision making criterion may be available, managers generally are able to specify their priorities with respect to organizational goals. Thus, common grounds for discussion are obtained by using the goal programming tool in the manner demonstrated in Section IV.

1.6 ORGANIZATION OF THE REPORT

The final report is organized to document the contractual effort as follows:

- Section II is a review of the literature on information service quantification techniques
- Section III is a goal programming model for DDC planning and decision analysis with respect to resource allocation problems and project evaluation. It demonstrates a basic methodology for measuring information services and relating then to organizational goals
- Section IV demonstrates the feasiblity for using the technique for DDC planning and policy analysis

Supporting materials and data are provided following the text.

- The bibliography lists the documents used in the contractual effort
- Appendix A documents the administrative interviews
- Appendix B defines the mathematical signs and symbols used in the goal programming model
- Appendix C presents data tables used in the construction of the DDC goal programming model
- Appendix D is a description of the computer solution program and the procedures for setting up problems for the computer

SECTION II. QUANTIFICATION OF INFORMATION SERVICE GOALS: A LITERATURE REVIEW

This section reviews the literature on the quantification of information service goals for use in *decision analysis.* the references, in parentheses, are made to the bibliography at the end of the report. The review is presented to summarize how far the field of information service has progressed in quantitative decision-making, and to characterize available tools for measuring information services. If goal programming is to be a practical aid to information service managers, it is essential that the managers become aware of what available techniques for measuring information services can contribute to decision analysis.

To serve this end, the review concentrates on the following topics:

- Progress to date
- Decision Models
- Measurement of information services

2.1 WHAT DECISION ANALYSIS ENCOMPASSES

Decision analysis may be interpreted in a general sense as the use of the scientific method to solve management problems, or in a

narrower sense as the application of mathematical techniques to management. The essence of decision analysis is model building. Decision analysis is distinguished from the generic field of operations research, (also called management science) by its emphasis on the need for an integration of quantitative analysis with environmental and behavioral aspects of the decision-making process. Therefore, decision science encompasses a broader spectrum of the decision-making process than the processes of quantification alone. It is in the broader context that this review has been conducted.

2.2 PROGRESS TO DATE

The literature of information service quantification and measurement techniques strongly suggests that the field has not progressed very far into decision science. Measurement techniques in the current literature concentrate on narrow aspects of operating systems. They usually lack the involvement of environmental aspects and organizational goals and objectives. Thus, they are not consistent with decision-making practices (Debons', 23).

Most reviewers of the state-of-the-art of quantitative evaluation of information services create a pessimistic impression with respect to progress made to date in collecting and using data for decision-making. Hindle and Raper (33), for example, conclude that the achievements in quantitative evaluation for analysis of informational policy must be regarded as "disappointing". They report a particular lack of methods to develop detailed knowledge of resource allocation problems. In this respect, they are supported by Ford (28), who concluded a review of research in user behavior by stating that "we have measured almost every conceivable characteristic of the user, but without any attempt to use these data to clarify resource allocation issues".

The progress that is conceded applies to the evaluation of public libraries and academic libraries (Hamburg, 31; Bommer 6; and University of Durham, 89). By contrast, the use of quantitative techniques for overall design and evaluation of specialized information services, such as DDC, appears to be virtually unexplored territory (Hindle and Raper, 33).

Despite such negativism, actual progress may be somewhat better than the progress perceived by the reviewers. Lynch (55) suggests that the practical art of information service management may be ahead of the research and theory. In practice, managers are forced to use intuitive judgement and uncomplicated quantification measures in decision analysis. In practice, they do reflect the influence of their operating environments. Moreover, model building has developed a growing interest in the past five years, although the number of practical applications are few. Bommer (7) suggests the problem preventing more wide-spread applications of quantitative techniques may be that too much attention has been devoted to the construction and solution of complex mathematical models which ignore the value of simple and direct measures that are actually more useful to the decision-maker. Lee (50), who has specialized in applying goal programming models to a wide variety of management problems, also advocates the construction of models which are "a great deal simpler than reality".

Furthermore, techniques that serve more to demonstrate the mathematical prowess of the modeler than to assist the decision-maker have a tendency to show up more readily in the literature than more direct and pragmatic techniques, which may partially account for the paucity of reports of practical techniques suited for decision analysis in information service organizations.

2.2.1 The Cause for Optimism

Swanson (86) provides additional optimism in an extremely well balanced and comprehensive review of the state-of-the-art of evaluation studies. Her only agreement with other reviewers is that additional investigation into quantitative decision-making is clearly warranted. She contends that although the state-of-the-art of evaluation studies is still deficient, the deficiencies are a result of the embryonic stage of the field's development, combined with the variety and complexity of the decision environment it must address in evaluating information services. She concludes:

"To date, investigators have had the resources to probe only a small part of the whole, trying to formulate methodology as well as acquire data. This is seen as an expected phenomenon in the emergence and development of a body of knowledge, and more piecemeal study is anticipated before patterns appropriate to particular types of study are discernible". (Swanson, 86 p. 154-155)

The progress that has been reported over the past six to seven years is actually encouraging and impressive despite the fact that decision analysis procedures, definitive observational techniques, units of measure and theories have not yet emerged. While it is not yet possible for an investigator or manager to go to the literature and find a "cook book" type of article that tells what to measure, how to measure and how to interpret the results, studies, such as Hamburg's (31) for example, show that the use of measurement for decision making in the information service environment is feasible.

2.2.2 Examples of Progress

Significant progress is noticeable in just the growing concern being expressed for understanding the reasons behind measurement. Particularly since 1972, investigators have shown increasing awareness of the importance of recognizing that different system goals mandate different evaluative measures. In addition, they recognize that failure to discuss goals with evaluation provides only superficial indications of system effectiveness (Ladendorf, 47).

Wilson (96) describes 1972 as the pivotal year marking the passage of an era in which management accepted on faith the value of information. By then, the literature began to reflect a serious need to measure the effects and contributions of information products and services. About this time, the purpose of measurement took new directions concerned with costs, benefits, and welfare economics.[1]

[1] Welfare economics attempts to assess the beneficial consequences of actions to groups or individuals served by the actions.

The measurement techniques then available in the information service field were inadequate for demonstrating the purposes and effects of information products and services. Evans, et.al. (25) were disturbed by the fact that tools developed to that time failed to make their use clear. Of the five to seven hundred studies they reviewed, very few identified the goals or the importance of a given service to the achievement of those goals. The early tools did not indicate what "good" information service provided. Consequently, management interpretations of the quantified data was difficult and confusing. They were further dismayed over a general lack of consideration for the total service program.

Lancaster (48) said about the techniques available in 1970 that they may not have been able to measure the value of what information services were doing but "what they are doing, they are doing very well". How well they were doing is debatable since he also questioned whether it was "up to us to discuss 'ultimates'."

Very soon after these reviews, investigators began to reflect the need to consider the "ultimates". Although the information science literature on evaluation continued to be dominated by studies on retrieval measures or cost analysis, the library science literature produced a series of outstanding studies involving the use of quantified measures for evaluation of overall system performance measured against goals.

Hamburg, et.al. (31) have produced the most practical and generalized methodology for overall information service program evaluation. to date. They describe a framework for planning and decision making in which operations and resources expressed within a program structure can be evaluated in terms of exposure hours. Exposure hours are the consequence of library programs. Exposure is measured as the sum of occurrences when individuals borrow documents, use them in-house, obtain them through interlibrary loan or receive reference assistance. The project goal was to maximize exposure hours for given resources. The main difficulty they encountered was in trying to express everything in terms of one measure.

DeProspo. et.al. (24) about the same time as Hamburg took a multidimentional approach to measurement indicating various user demands on library resources. The factors they measure are traditional library elements: hours, circulation, use of equipment, and so forth. This study is an example of the use of uncomplicated, although not simplistic, measures to provide meaningful management data. They do not attempt to create a single dimension unit of measure, but they make the point that while their several measures indicate the use of library resources, the managers must determine whether these measures express operational objectives, and if so, what the criterion levels are for satisfactory operation.

The use of measures for program evaluation across several loosely interdependent organizations was implemented in the academic library environment by the MRAP (Management Review and Analysis Program) (Webster, 93).

Bommer (6) has built upon the sophisticated work of Morse (62) and developed a management system for effective decision making and planning in a university library.

2.2.3 Implications for Current Investigations

Three significant conclusions can be reached as a result of the progress in information service measurement since 1972:

1. Although it is necessary to develop a unique methodology in order to use quantification techniques successfully, those organizations able to commit sufficient resources to the task can implement useful programs. There are no intrinsic impediments in the nature of information service itself (Hindle and Raper, 33; Leimkuhler and Billingsley, 53; and Swanson 86).

2. The complexity of decision making in the information service environment is a significant problem which can benefit from the use of well planned quantification techniques (Buckland 10, Cooper 19, DeProspo 24, and Millham 59).

3. Although methodology (how to collect and use measures) is important, it is secondary to the rationale behind a study (what to measure and why). Moreover, when quantification is not considered in relationship to goals and objectives expressed as performance criterion, no methodological sophistication can cure conceptual deficiencies (Swanson 86, Smith and Wechsler, 81).

2.3 DECISION MODELS

Model building provides the conceptual framework to coordinate all that is known about various aspects of an organizational environment. Therefore, models facilitate decision-making in accordance with overall objectives. The term "model" is often used loosely to refer to any attempt to conceptualize such a framework. However, for decision analysis applied to this study, the most useful models are mathematical in nature. The use of mathematics is important not only for defining and measuring important system variables, but also for the power of mathematical theory which helps maintain consistent patterns of problem conceptualization throughout the decision analysis process.

Mathematical models relevant to the DDC environment are reviewed in this subsection.

2.3.1 Resource Allocation Models

The resource allocation problem has been addressed by Bookstein (5). His approach combines queuing theory and dynamic programming, which is not well suited to the current capabilities of the goal programming approach. Moreover, the mathematics are somewhat complex and the data needed to implement the model need to be determined through a systems analysis of alternative program designs. Consequently, the application of the model to routine problem solving is likely to be limited. However, the model is notable because Bookstein provides an interesting quantitative model of two important information service problems: (a) the optimal allocation of resources to sequential processes such as those for inputing data and documents into an information system; and (b) the optimal distribution of computer terminals according to work-load patterns.

Another relevant approach to the resource allocation problem is suggested by Crecine (20) in an application from outside the information service field. Crecine looks at resource allocation in the context of a municipal budgeting problem. Using a simulation model, he describes an approach to computer-aided problem solving involving the allocation of public resources to proposed programs on the basis of non-market factors. The approach is practical. It takes into account the political nature of public resource budgeting and works on the principle of achieving a balanced budget rather than attempting to meet some nebulous criterion of public satisfaction.

The distinction between political choice and market choice is an important one to remember in selecting practical performance criteria for program evaluation involving public resources. This issue is further explored by Raffel (72) and Vickers (91).

2.3.2 Information Center Location Problem

Kraft and Hill (45) describe a location model for optimizing the placement of information centers. The model is formulated as a linear programming problem. It is an interesting model because of its possible applicability to the problems of locating remote terminal access centers for the defense RDT&E community.

Kochen and Deutsch (43) make an attempt at a general quantitative theory of decentralization applicable to information service facilities. They express the number of facilities as a function of demand rates, distances, speed and cost of transport, the value of waiting for results and the costs of decentralized facilities. The model tends to suggest smaller, more numerous and more dispersed facilities.

2.3.3 Economic Models

Scholz (80) recently described a methodology that could be useful for calculating the probable effectiveness of various data bases in meeting DDC user needs. This type of data would be helpful in determining whether or not new data bases should be added to DDC's basic

service program. However, the report is preliminary and its practicality will have to be judged after the general model is completed.

Price (69) presents a rather flexible model that he claims can be used for a wide variety of cost control projects.

A study currently in progress at Purdue University (71) is directed toward a financing and pricing policy for industrial information analysis centers (IAC). A broader, though less detailed view of industrial IAC resource allocation is also reported for future application in a decision-making model. The model seems to be inclined toward the use of user satisfaction criteria.

2.3.4 Decision Models for Library Services

This section highlights the more significant library service models. Morse (62) provided the earliest significant work on quantification of library service for decision-making. His formulations address most of the traditional library functions such as book selection, circulation and collection uses. Morse recognized a number of limitations in his units of overall measure that use past records of demand to predict future demand. However, much of the subsequent work on library models relied on Morse (Bommer (6); Hamburg, et.al., (31).

A second early study, the PEBUL project (Project for Evaluating the Benefits from University Libraries, 1969) demonstrated that benefits from libraries can be measured by observing users' behavior in conjunction with administrative decisions. In this manner the PEBUL methodology successfully applied quantitative techniques to attributes of performance (University of Durham, (89).

Hamburg, et.al. (31) developed an outstanding quantitative approach to the problem of evaluating information service problems in a decision-analysis context. They provide for both behavioral and environmental considerations in their approach to optimizing a measure of exposure hours calculated for the various library functions. Their only limitations are those inherent to the unidimensional aspects of measuring all output of the library in terms of one unit of measure. The methodo-

logical difficulty of formulating a very complex problem in terms of a single unit of measure was explored by Huber (34) as well as Charnes and Cooper (14). Investigations similar in methodology to Hamburg et.al. were carried out in the university library context by Bommer (6), Buckland (8), Burr (12), and Kantor (37).

A number of investigators addressed the problem of how to structure a program in order to make the most from available resources. Urquhart (90) discusses the broad prospects for information services in competing for national resources and suggests that planning must be dictated by the limited available resources. Millham (59) and Rouse (75) describe models for the public library and a university library respectively to assist in conducting a trade-off analysis among alternative programs measured against a set of management criteria.

NELINET used operations analysis of its internal processes in combination with a market-research methodology to evaluate potential products and generate data that were used to make decisions about its line of products and services (New England Board of Higher Education, 64).

2.3.5 The Goal Programming Approach to Model Building

Goal programming as described by Lee (50) was selected as the decision analysis technique to be the subject of this study because it is a relatively new technique that has the wide application potential of linear programming but is a great deal more flexible. Moreover, goal programming permits the simultaneous consideration of multiple goals which is highly consistent with actual DDC management practice.[3]

Where a decision analysis model is to be used in a complex management environment, the quantitative technique used should be capable of handling multiple decision criteria. The linear programming technique of mathematical modeling has a limited value for problems involving multiple goals.

[3] The principles of goal programming are discussed in Section III, but for comprehensive comparison of goal programming versus linear programming see Lee (50).

The problem is apparent in the information service environment when one considers that the unidimensional nature of the work of Hamburg, et.al. (31) is the major practical limitation in that significant effort. To overcome the unidimensional nature of the model, it is necessary to convert incompatible goals such as cost, circulation and document access into one criterion, namely exposure hours. In a practical sense, it is extremely difficult to measure such incommensurate goals as a single unit of measure, namely a utility function. Thus, decision making based on models employing utility functions, is feasible more in theory than in practice.

While a comprehensive review of goal programming is not within the scope of this review, a brief history of the evolution of the technique is provided for the reader who wishes to understand its origins.

2.3.5.1 The Evolution of Goal Programming

Goal programming is derived from linear programming. It emerged from the work of Charnes and Cooper (14) in the 1950's. The name was given to the technique in their well respected book on applications of linear programming to industrial problems. The concept of programming to goals first emerged as an issue for unsolvable linear programming problems. Charnes and Cooper describe the concept as follows:

> "Closely related to the analysis of contradictions in unsolvable problems is the issue which will be called "goal attainment." Management sometimes sets such goals even when they are unattainable within the limits of available resources for a variety of reasons...Any constraint incorporated in the functional will be called a "goal". Whether goals are attainable or not, an objective may then be stated in which optimization gives a result which comes as close as possible to the indicated goal." (Charnes and Cooper, (14)p.215-216).

Charnes and Coopers' role was primarily in popularizing linear programming through their success in formulating a wide variety of problems using linear programming techniques. As a result, the practicality of using linear programming for managerial decision-making

was firmly established.

The origins of linear programming can be traced far back in mathematical history to the theories of linear and non-linear equations.[4] However, in modern history, George Danzig is credited as the "father of linear programming"(Lee, 50).

Danzig's work was primarily in the search for techniques to solve logistics problems for military planning. He formally introduced the "simplex method" for calculating solutions to linear problems at a 1951 Conference sponsored by the Cowles Commission for Research in Economics (Koopmans, 44).

People recognized by Danzig as instrumental to his success were his associates Marshall K. Wood, Leonid Hurwicz, and Tjalling C. Koopmans. Also, he cited the work of John Von Neumann in game theory (Danzig, 22; Koopmans, 44).

More recently, the acceptance and utility of linear programming was enhanced by the work of Charnes and Cooper (14). Then, the goal programming aspects were improved by Ijiri (13) who added the concept of pre-emptive priorities to the solution of conflicting goals[5]. Contini (18) examined the goal programming method under conditions of uncertainty (stochastic methods). Jaaskelainen (36) used goal programming to solve production planning problems. Pitkanen (67) explored goal programming's application to public administration and Ruefli (77) has been working with Charnes on the application of linear programming to the popular Planning-Programming-Budgeting System (PPBS) in which goal programming is likely to apply. Trinkl (87) has also explored the applicability of goal programming to PPBS.

Lee (50) has become a major contributor to the practical application of goal programming to real world problems. He provides numerous

[4] For a general presentation of the basic principles of linear programming see Churchman (15).

[5] The significance of pre-emptive priority is made clear in Section III.

examples of model formulation and goal quantification techniques to serve as guides when formulating new problems. In addition, he provides a FORTRAN computer program based on the simplex method for calculating solutions to goal programming problems. It also features Ijiri's principle of pre-emptive priority for finding optimal solutions.

Lee appears to have made a significant contribution to decision science by making goal programming a practical management tool for use by imaginative investigators and managers.

2.4 MEASUREMENT OF INFORMATION SERVICE

Measurement is important in the decision analysis process because it provides the content of the mathematical formulations of the model. Numerical data serve to establish quantitative relationships among the components of the decision-making system represented by the model. Too often, the functional nature of measurement is overlooked and an unwarranted mystique is attributed to the numbers holding them to be absolute values. What is needed for decision-making is the simplest measures which will suffice for deriving pragmatic relationships in the decision problem.

The point was made previously in this report that standard measurement techniques for evaluating information service programs do not exist. Neither is there concensus on the type of measurement techniques appropriate to particular types of study. Consequently, it is not possible to clearly relate the measurement techniques reported in the bibliography to DDC problems. Nor is it possible to obtain from the literature measures of information services which are universally applicable to the goal programming approach. Therefore, studies which attempt to measure information service factors in a scientific fashion have been included in the bibliography mostly to serve a reference function and stimulate DDC management's thinking about meaningful quantitative techniques for use in decision analysis of problems that arise subsequent to the present effort.

Nevertheless, to employ quantitative techniques on a practical level, it is important for the information service manager to understand the characteristics of valid measures and also to consider the types of

measures that have been employed usefully in other goal programming formulations.

2.4.1 Characteristics of Valid Measures

2.4.1.1 Functionality of Measurement

Quantification in evaluation is often looked upon as a means of ensuring objectivity in the evaluative process. Certainly, it is an aid in that respect but quantification alone will not ensure it. Nor is objectivity related to the exactness of the measures used. The nature of measurement is characterized by Kaplan:

> "Measurement, in short, is not an end in itself. Its scientific worth can be appreciated only in an instrumentalist perspective, in which we ask what ends measurement is intended to serve, what role it is called upon to play in the scientific situation, what functions it performs in inquiry.
>
> "The failure to recognize this instrumentality of measurement makes for a kind of mystique of quality, which responds to numbers, as though they were the repositories of occult powers." (Kaplan 38, p. 171-172).

In a later passage, Kaplan adds that "exactness is not as important for scientific status as is objectivity."

Thus, measures are seen to be instruments in decision analysis and a variety of techniques may be equally appropriate for a given situation and purpose. The validity of the measure according to Kaplan (38) rests in whether the measure has value to those using it and they can "do something meaningful with it." Thus, the first characteristic of valid measurement is that validity depends on the context in which the measurement is used and the inferences taken from it.

2.4.1.2 Quantified Evaluation

Quantification used for evaluation is merely the use of numbers to measure value. Inherently, it involves a combination of basic assumptions underlying the activity being evaluated. Thus, for evaluation, measures represent approximations of value (Suchman, 83).

Certainly, to transform qualitative information service values into measurable factors requires a reasonably precise definition of "qualities" such as comprehensiveness, timeliness, accessibility and user satisfaction. Precision in this sense means to artificially establish a value scale. Evaluative measurement can then be made in ordinal or comparative terms if need be. Such measures may lack exactness, but if they are used objectively they are valid in a true scientific sense.

Consequently, a second characteristic of valid measurement is that it may have a subjective basis if the measures are applied uniformly.

2.4.2 Measures Useful in Decision Analysis

Decision analysis does not substitute for judgement in decision-making. The value of intuitive judgement based on the experience of the decision maker who has proved his ability is a valid source of measures useful in decision analysis. Numerical procedures may include very primitive measures based on management judgement or measures derived through a very systematic analysis. In fact, the process of decision analysis may help refine an initial set of measures based solely on management's intuitive judgement to a well scaled measurement system.

Numerical procedures are based on three steps:

1. Assignment of measures of value to the decision variables expressed in the form of a mathematical model which establishes relationships among the variables
2. Analysis of model solutions
3. Selection of the set of values for the decision variables that yield the most satisfactory solution

An iterative trial and error analysis employing alternative measurement schemes may well result in a sharpened perception of a decision problem leading to a measurement system particularly meaningful for some operational function that had not been quantified previously. (Lee 50).

Decision analysis takes a pragmatic approach to quantification. It employs measures of only the essential elements of the problem being

modeled, and then using the modeling process, searches for a formulation to use the available data (Lee, 50). Consequently, the development of a practical decision analysis model need not wait until exact measurement schemes are developed to fit the decision problem. The main prerequisite for using the pragmatic approach to measurement is that management must be willing to express at least an ordinal importance for goals in a linear decision system.

2.4.3 Measures for Goal Programming

Pitkanen (67) describes a very intesting application of goal programming in the area of policy analysis relevant to the DDC environment. This model was concerned with setting goals related to public expenditure decisions. Pitkanen regarded the quantification problem as one of setting targets for desired levels of resource utilization from several pools, and targets for output in terms of consumption goods and services (those that are part of the basic public program) and investment goods and services (those designed to improve the services themselves). The focus of his study was on establishing priorities for various incompatible and incommensurable objectives. Pitkanen emphasized that the goal programming approach had general applicability in public administration by ensuring that in the planning process, the goal setting problem would go before the detailed preparation of the plans. Coincidentally, Mintzberg et.al. (60) pointed out the significance of Pitkanen's observation following an intensive study of 25 strategic decisions. They conclude that organizations tend to formulate only one fully detailed option to submit for evaluation. They find that goals tend to be formulated with precision after the decision has been made and not before.

Gibbs (30) used goal programming in the situation where a corporate computer systems and planning group desired to develop a training program for its systems analysts. His model solved a resource allocation problem with respect to the use of contract services versus in-house staff based on relative cost and effectiveness measures. Gibbs used a standard linear programming computer solution package. Therefore,

in order to give priorities to his goal statements, he had to provide a weighted measure of the relative value of each goal rather than a simple ordinal ranking. However, his model did provide valid solutions to the problem he posed.

Lee (50) provides the most comprehensive set of applications of goal programming to practical problems. The list of his accomplishments includes:

1. Production Planning - the production of record players and tape recorders.
2. Financial Planning - management of capital structure, dividend payout policy, and growth of earnings over a multi-time phase period.
3. Mutual Fund Portfolio Selection - to account for expected return and market volatility.
4. Management Decisions - the scheduling of management and sales force staff in a specialty shoe store.
5. Media Planning - the allocation of resources to advertising programs for the promotion of sales.
6. Corporate Planning - overall management planning of revenue and expenditures in a public utility.
7. Academic Planning - resource allocation of various classes of labor to meet set criteria of accreditation and program budget requirements.
8. Decision Analysis in Government - a multi-year model for revenue expenditure and capital improvement planning in a small city.
9. Budgetary Planning in Health Care Clinics - the allocation of various classes of labor resources to program goals.
10. Resource Allocation in Hospital Administration - a multi-year model for long range planning at a 200 bed hospital in a small city.

Of Lee's models, the academic planning-resource allocation model (Lee, 51) seems to provide the most applicable approach to the kind of decision environment identified in the Administrative Goal Survey that was the initial task of the present study.

Lee's models include a wide variety of application areas which could be applied to analogous problems in information service organizations such as DDC. Each model characterizes a complex set of widely

varied and competing goals as well as a methodology for quantifying the essential factors involved in the decision problem. The diversity exemplified by the list demonstrates the range and flexibility of the goal programming decision analysis technique.

SECTION III. A GOAL PROGRAMMING MODEL FOR DDC PROGRAM EVALUATION

3.1 INTRODUCTION

This section presents a general goal programming model for program evaluation in DDC's decision-making environment.

Goal programming uses a mathematical approach to resolve decision problems. Its main feature is mathematical model building.

From the outset of the model building effort, the decision problem is conceptualized in mathematical form.

The model is complete when the entire decision problem is arrayed as a matrix of measurable factors consisting of a set of equations with goal criteria[1] on the right hand side of the equations and the relationships of the decision variables[2] to the goal criteria expressed on the left hand side.

[1] Goal criteria as used in this report are numerical constants that represent quantified performance goals against which program evaluation analysis can be made.

[2] Decision variables are the program resources under the decision-makers control.

It is the purpose of this section to present such a matrix relevant to DDC.

Measurement is important as providing meaningful content (meaningful to the decision-maker) for the mathematical forms which are employed. For example, the goal criteria must be defined in such a way that they allow a means for quantitative evaluation of DDC's organizational and administrative goals. Moreover, relationships within DDC's decision environment and DDC's operating program must be quantitatively related to organizational and administrative goals.

Frequently, descriptions of quantitative analysis techniques are initially confusing. This is perhaps due to the symbolic notation required to formulate the problem under consideration. As the DDC model is developed, hopefully, this confusion will be cleared up. In an effort to alleviate this inherrent problem, Appendix B is provided to define some of the arbitrary signs and symbols used in the notation. In addition, the following introductory sub-sections will review the concept of model-aided decision-making in a functioning organization, establish the DDC context of the program evaluation model, and explain the general goal programming model form. Following the introductory material, the model developed for DDC is presented.

3.1.1 Organizational Goals and Model-Aided Decision-Making

Figure 3-1 is a functional diagram of the organizational decision-making environment of a service unit in a bureaucracy. It shows that organizational decision-making begins with a need to do something. At the highest level the need results in the creation of the organization itself. All other decisions are hierarchically related to the need which created the organization in the first place.

The organizational needs can be stated as goals and these too are hierarchical. Administratively, the goals translate into a set of programs intended to carry out the goals.

As the diagram shows, the goals are concerned with why an organizational program is being carried out, not the means by which

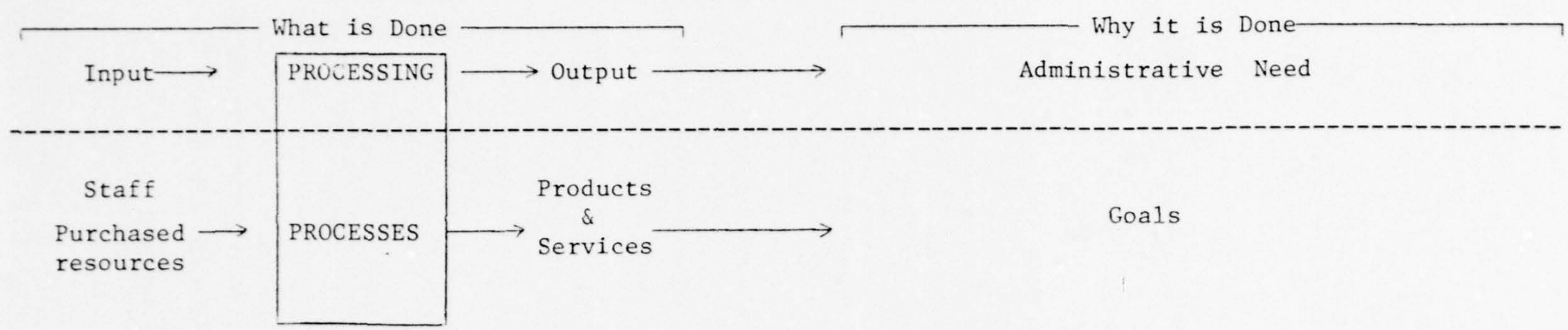

Figure 3-1. Organizational Decision Making Environment

it is done. Consequently, a goal program structure meaningful to organizational decision-making must be one stated in terms of why a program exists or is being proposed, rather than how an administrative unit will accomplish some task, if the goal program is to have meaning at administrative levels superior to the operating unit.

It should also be noted that because of the hierarchical nature of an organizational goal structure, goals are introduced into the system at many points in the organization. It is not surprising then, that valid organizational goals are often competitive and conflicting at the point where they must be translated into operating programs.

The program administrator's job, in this instance the DDC Administrator, is to balance the use of available resources among various processing operations and satisfy as many organizational goals as possible.

For an information service unit this means the output of products and services. The input consists of staff, computer resources and purchased materials. At DDC this constitutes the annual Program/Budget.

The administrator may use experience, intuition, data or all three to make program decisions, which involve weighing the probable consequences of alternative actions and choosing a course of action "best" for a given situation. The process is part management art and part science. The artful process by which a program is conceived, is paramount. Management science supplements the art by making data and facts available to the manager to aid the decision-making process.

3.1.1.1 Role of the Decision-Analysis Tool

The decision analysis model is a management science tool that can supplement the traditional decision process in these key ways:

- It provides a means of defining the decision environment by establishing a working cause and effect relationship between resources, processes, output and goals.

- It provides a means of systematically considering a wide variety of alternative decision strategies, including the reordering of goal priorities, the realignment of resource allocations, the consequences of increasing or decreasing the level of resource categories.

- It ensures that all key elements in the decision environment are considered each time a decision is considered.

- Model-aided decision-making creates a documented record of the decision process at each level in the administrative negotiations required to arrive at an operational plan. Such a record can serve as a measure of accountability.

- As a mathematical model, it will provide quantitative solutions to management problems such as the total budget requirements to meet all goals, and the number of resources that should be allocated to programs.

- A goal programming model's most interesting feature is that it helps establish priorities for proposed operating programs. This feature is demonstrated in Section IV.

3.1.2 Steps to Implementation of the Goal Programming Model at DDC

In order for a decision analysis model to be practical in the DDC context, it must be flexible enough for DDC's environment and must be capable of reflecting the management's judgements in lieu of objective measures of value for information products and services. In addition, the contributions of various program projects to goal attainment must be considered in making resource allocation decisions among projects - particularly when new projects are to be introduced. Finally, it must be able to consider the overall DDC program in program evaluation analysis.

The goal programming approach to decision analysis meets these criteria. However, it requires (1) a definition of organizational goals; (2) a definition of organizational objectives; and (3) a quantitative representation of the real decision problem in symbolic mathematical form. With these inputs the goal programming model is used to analyze real decision problems and calculate solutions.

It should be recognized that a mathematical model should be a great deal simpler than reality to understand and manipulate. Otherwise, it would be no more useful in decision-making than dealing directly with the problems. Thus, the model solutions must be considered as approximate solutions subject to management interpretation in the real-world environment.

3.1.2.1 Inputs to the Model

The goal programming model's parameters were derived by AAI from analysis of the results of the administrators' goals survey summarized in Appendix A. The survey results were augmented in subsequent discussions with DDC managers. Essentially, the administrators' goals were assumed to be organizational goals.

Organizational goals inferred from the administrators' interviews were made functional[3] for goal programming analysis by (a) devising a goal structure (Table 3-1) to provide a conceptual framework for relating DDC products and services to organizational goals, and (b) working with DDC to list operational objectives (Table 3-2). The operational objectives specify the goals in order that the degree of attainment can be evaluated.

The next step leading to the goal programming model formulation is to define decision variables and goal criteria as factors of organizational goals and objectives. For this study, the decision variables are essentially the program projects in the DDC Program/Budget[4]. A complete table of the decision variables for this study is provided as Appendix C, Table C-1.

DDC chose to use the data for the 1978 Program/Budget in this effort. The model can be used with any year; but of course, the variables, goal criteria and some of the constraints might be different. In fact, any project list meaningful to DDC management can be utilized as

[3] "Functional" means that the Administrator's goals and DDC products could be correlated using the goal structure as a common point of reference.

[4] Defense Documentation Center, Research, Development, Test and Evaluation (RDT&E) Program/Budget, Fiscal Years 1976/1977/1978. 27 August 1976. Defense Supply Agency, Department of Defense, Washington, D.C.

TABLE 3-1. GOAL STRUCTURE FOR DECISION ANALYSIS[5]

Goal 1: Projects to Aid in Identifying and Locating Information as Opposed to Documents (Basic and Investment Effort Desired)

- To RDT&E Managers
- To Scientists and Engineers

Goal 2: Projects to Provide Access to DDC Held Documents (Basic and Investment Effort Desired)

- To RDT&E Managers
- To Scientists and Engineers
- To Non-DoD Users

Goal 3: Projects to Provide Access to Documents/Information from Remote Locations

Goal 4: Projects to Promote Use of Information Products and Services

- Among RDT&E Managers
- Among Scientists and Engineers
- Among Non-DoD Groups

Goal 5: Administration

- To Administer DDC Services
- To Plan DDC Services
- To Prepare Programs, Projects and Budgets
- To Set Target Levels for the Output of Products and Services
- To Provide Systems Support

[5] Source of data: derived from Administrators' interview (Appendix A).

TABLE 3-2. DDC OPERATIONAL OBJECTIVES [6]

1. Maintain the necessary resources to produce a basic level of products and services.
2. Provide resources for investiment projects intended to improve the present level of service.
3. Utilize contract services to supplement in-house staff if necessary.
4. Reduce the DDC costs for input activities relative to output costs.
5. Provide resources to analyze and promote use of DDC's products and services.
6. Except for major equipment acquisitions, limit budget increase requests to no more than 5-10% in any one budget planning period.

[6] Source of data: Selected in concert with DDC management.

decision variables in the model in later applications so long as the data appropriate to a given list are input to the model.

The goal criteria are numerical constants representing quantified performance goals. They are set by management and specify how management wants to see the resources used. They may be either available resources or specified target levels. They may also be in conflict with one another.

Six types of goal criteria related to the administrators' goals and DDC's operational objectives were jointly selected for this study by the modeler and DDC. The model evaluates proposed programs against these criteria:

- The labor resources in man-years available for 1978 programs
- The Budget available for 1978 programs
- Labor resources available for projects to produce DDC's basic products and services
- Resources available for projects to improve the level of DDC services as an investment for the future
- Target levels for the distribution of man-years among projects to achieve a balanced program considering:
  - Services to RDT&E managers relative to scientists and engineers
  - Services to support libraries
  - Responsiveness to the organizational goals identified by administrators (Table 3-1)
  - Responsiveness to users
- Specified target levels for the number of man-years to be allocated to specific projects

The model allocates resources to proposed projects in an attempt to simultaneously meet all stated goal criteria. Where there is conflict and not all goals can be fully served, choices will be made on the basis of priorities assigned to the goal criteria by the Administrator.

Through application of goal programming, the DDC decision-makers will be able to measure the soundness of a program relative to

organizational goals, the resource allocation requirements for achievement of the goals and the degree of goal attainment possible with a given limitation of total resources.

3.1.3 General Mathematical Form of the Goal Programming Model

Goal programming is a special version of linear programming which is a highly developed set of techniques and algorithms particularly useful for decision problems involving resource allocation. Linear programming is concerned with finding optimal solutions to problems with linear objective functions and linear constraints.

A linear programming problem must have either a single objective function (one "goal" to be satisfied) or multiple objectives, all of which can be reduced to a single effectiveness measure (unidimensionality).

On the other hand, goal programming handles multiple goals in multi-dimensions. The difference is in the form of the goal programming model. Each "goal" is formulated as a "constraint". The left hand side of the constraint/goal consists of the decision variables and their coefficients, plus negative and positive slack variables. The slack variables, if they take on any values in the solution, indicate deviations from the goal criterion. The goal criterion is stated as one number on the right hand side of the constraint equation.

The objective is stated in terms of the slack variables (d_i). Management must specify the priorities of avoiding underachievement and overachievement of each goal. The objective, then, is to minimize the total value of the slack variables (represented by Z) designated by management and thereby avoid deviations from the goal criteria.

The general goal programming model can be expressed mathematically as:

$$\text{Minimize} \quad Z = \sum_{i=1}^{m} (d_i^+ + d_i^-) \qquad \text{(objective)}$$

$$\text{Subject to:} \quad A_{ij}X_j - d_i^+ + d_i^- = B_i \qquad \text{(goal/constraint)}$$

However, for the purpose of explanation, a somewhat less condensed version will be introduced to show the matrix structure of:

$$A_{ij}X_j - d_i^+ + d_i^- = B_i$$

For example:

$$\text{Minimize} \quad Z = \sum_{i=1}^{m} (d_i^+ + d_i^-)$$

Subject to:

$$A_{11} X_1 + A_{12} X_2 + \ldots . + A_{1n} X_n - d_1^+ + d_1^- = B_1$$

$$A_{21} X_1 + A_{22} X_2 + \ldots . + A_{2n} A_n - d_2^+ + d_2^- = B_2$$

$$\begin{array}{cccccc} \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \end{array}$$

$$A_{m1} X_1 + A_{m2} X_2 + \ldots . + A_{mn} X_n - d_m^+ + d_m^- = B_m$$

$$X_j,\ d_i^-,\ d_i^+ = 0 \text{ for all } i, j$$

where:

B_i are the m goal criteria

X_j are the n variables associated with the m goals. These are the variables of interest in the problem (the decision variables, the proposed projects)

A_{ij} is an n x m matrix of the coefficients on the n variables which express the relationship between decision variables and the m goals

d_i^+ is the amount of positive slack (over achievement) in goal i

d_i^- is the amount of negative slack (under achievement) in goal i

To form the objective function, which is the final step in completing the model, the slack variables d_i^+ and d_i^- must be ranked according to their preemptive priorities from the most important to the least important. In this way the lower priority goal criteria will be met only after higher priority goal criteria. If there are k priorities they have the relationship.

$$P_1 >>> P_2 >>> \ldots >>> P_k$$

This means that the minimization of the value of d_i^+ and d_i^- associated with P_k will always be considered less important than the minimization of the value of d_i^+ and d_i^- associated with P_{k-1}.

A final note which should be made concerning the objective function is that within priorities (each P_k) further differentiation is possible by assigning numerical weights to the various slack variables. In this way, one goal's achievement could be said to be, for example, twice or three times as important as another.

But now, let's turn to the DDC model.

3.2 THE DDC GOAL PROGRAMMING MODEL

The fundamental model has been based on the planning data for the 1978 Program/Budget and the goals and objectives in Table 3-1 and 3-2.

The projects listed for the 1978 program make up the basic table of decision variables. The Program/Budget list has been slightly modified to call out three sub-projects of particular interest to DDC:

- the establishment of on-line terminal service in Boston
- the establishment of on-line terminal service in Los Angeles
- the promotional effort requiring 4 billets in project 5.1

The complete table of the decision variables is provided as Appendix C, Table C-1. The goal criteria are stated with their respective constraints. The source of the data is summarized in Appendix C, Table C-2.

For the model formulation, the following constraints are derived:

A. Total Number of Staff

The total resources available in the 1978 budget is 454 man-years. This is a desireable target level. However, among the operational objectives it was indicated that the absolute limit on resource increases is 10% over the previous year. Since labor is the dominant budget element in the DDC program. A constraint is formulated to set the absolute limit of 491 (10% over 1977) on the number of man-years. A second constraint is formulated for the more flexible goal criterion 454.

Since it is known that in-house positions are more difficult to justify them total dollar increases, the difference between 454 and 491 could be considered a recommendation to supplement in-house staff with contract staff should the solution exceed the 454 goal criterion.

- goal criteria (a_j):

  a_1 - maximum staff considered feasible (491)

  a_2 - desired number of staff (454)

A.1 Maximum Feasible Staff

$$\sum_{i=11}^{26} x_i + \sum_{i=31}^{45} y_i + \sum_{i=51}^{60} z_i + d_i^- = a_1 \qquad (1)$$

A.2 Desired Number of Staff

$$\sum_{i=11}^{26} x_i + \sum_{i=35}^{45} y_i + \sum_{i=51}^{60} z_i + d_2^- - d_2^+ = a_2 \qquad (2)$$

where (for all formulations):

x, y, z = man-years allocated by the model to the i projects in Appendix C, Table C-1 (the decision variables)

i = subscript to identify the respective projects individually. The numbers refer to those used in Table C-1 which are based on the project/sub-project code numbers in the DDC Program/Budget in order to aid managements' understanding of the model. The subscript indicates the first project to be included in the summation (Σ) and the superscript indicates the last

a_j = goal criteria. The actual value to be used is indicated in parenthesis.

d_i = deviational variables. Note that d_i^+ has been deleted from the initial model to indicate that any solution in excess of 491 would be unfeasible.

B. Total Cost

The cost constraint can be assigned the lowest priority and set to zero in order to calculate the total cost of achieving all other goals. If the solution then exceeds a feasible cost, a budget figure can be entered as a goal criterion on the solution.

Since labor is the principal cost item insofar as DDC decision-making is concerned, the labor cost alone is the most relevant cost figure to use as a goal criterion. It is assumed that in-house and contract staff costs are equal.

- goal criterion (a_j):

a_3 - Total Labor Cost (zero or $8,778,000)

$$\sum_{i=11}^{26} c_i x_i + \sum_{i=31}^{45} c_i y_i + \sum_{i=57}^{60} c_i z_i + d_3^- - d_3^+ = a_3 \qquad (3)$$

where:

c_i = a one row matrix of labor cost coefficients (Total project labor cost/no. of man years). The figures calculated for the 1978 budget are shown in Table 3-3.

TABLE 3-3. LABOR COSTS FOR 1978 PROJECTS

Variable	C_i
x_{11}	13.92
x_{12}	19.85
x_{13}	20.0
x_{15}	16.0
x_{16}	20.0
x_{17}	17.0
x_{18}	15.50
x_{19}	21.74
x_{191}	21.74
x_{192}	21.74
x_{21}	18.01
x_{22}	14.1
x_{23}	15.65
x_{24}	17.0
x_{25}	25.0
x_{26}	21.43
y_{31}	0.0
y_{32}	27.0
y_{33}	23.60
y_{34}	23.0
y_{41}	29.80
y_{42}	21.71
y_{43}	22.05
y_{44}	23.0
y_{45}	22.16
z_{51}	20.4
z_{511}	20.4
z_{52}	23.84
z_{53}	13.0
z_{60}	19.07

To calculate the total cost, the analyst needs to add the value of non-labor costs to the labor costs calculated by the model:

$$\text{Total Cost} = a_3 + (d_3^+ - d_3^-) + (\text{non-labor costs}) \qquad (4)$$

C. Basic Services

An effective basic program of products and services must be maintained to keep the confidence and support of the top administration as well as supplying current service demands.

Two goal criteria are of interest to calculate the basic service requirements:

- goal criteria (a_j):

  a_4 = Proportion of the total service program desired for basic services (85%)

  a_5 = No. of man-years available for basic services (363)

C.1 Percentage of the Total Program that is Classified "Basic"

Since: $\dfrac{\text{Labor Resources for Basic Projects}}{\text{Total Service Program Labor Resources}} = a_4$

then: (Labor Resources for Basic Projects) = a_4 (Total Service Program Labor Resources)

Formulated for the study model this becomes:

$$\sum_{i=11}^{26} x_i + .80\,(y_{41} + y_{42}) + .40\,y_{43} + .50\,y_{44} + z_{52}$$

$$- a_4 \left[\sum_{i=11}^{26} x_i + \sum_{i=31}^{45} y_i + y_{52} \right] + d_4^- - d_4^+ = 0 \qquad (5)$$

where it is specified that projects y_{41}, y_{42}, y_{43} and y_{44} have both basic and investment elements represented in their labor resources. The respective proportions of basic service are indicated in the constraint and also in Appendix C, Table C-1.

C.2 Formulation of an "Effective" Basic Program Constraint

The number of man-years available for basic services in 1978 is targeted at 363. If it is assumed that there is a direct linear relationship between labor input and service output then a constraint can be written such that the individual projects are allotted some resources from the pool of 363 according to their effective contributions to meeting overall performance goals.

Using the same specifications as in equation (5), equation (6) can be written:

$$\sum_{i=11}^{26} E_i x_i + .80 \; (E_{41}\, y_{41} + E_{42}\, y_{42}) + .40 \; (E_{43}\, y_{43}) + .50 \; (E_{44}\, y_{44}) + E_{52}\, z_{52} + d_5^- - d_5^+ = a_5 \qquad (6)$$

where E_i represents a measure of probable effectiveness calculated for each proposed project. The values of E_i that have been calculated in concert with management, are shown in Table 3-4. The data used to calculate the elements of E_i, e_1 and e_2, are shown in Appendix C, Table C-3.

It is assumed, for the constraint, that DDC wishes to maximize service by putting its resources into the most effective programs. Projects with high E_i values will tend to draw resources over those with lower scores. For example, output oriented projects are favored over input projects. On-line services are favored over other information projects. It is not necessary to rely solely on the effectiveness coefficient (E_i) to allocate resources to all projects. Some project elements such as administrative and support elements are more easily incorporated into later constraints because their effectiveness is difficult to measure directly.

TABLE 3-4. PROBABLE EFFECTIVENESS COEFFICIENTS (BASIC PROGRAM)

Variable	e_1 Effectiveness factor scores	e_2 Management's willingness to commit resources*	$E_i = \pi\, e_1 e_2$
x_{11}	2	.028	.056
x_{12}	7	.028	.196
x_{13}	6	.002	.012
x_{15}	2	.004	.008
x_{16}	5	.002	.01
x_{17}	1	.009	.009
x_{18}	5	.004	.02
x_{19}	8	.033	.264
x_{191}	7	.004	.028
x_{192}	7	.004	.028
x_{21}	4	.199	.196
x_{22}	7	.022	.154
x_{23}	7	.136	.952
x_{24}	7	.015	.105
x_{25}	4	.002	.008
x_{26}	9	.05	.45
y_{41}	4	.011	.044
y_{42}	4	.015	.06
y_{43}	6	.042	.168
y_{44}	5	.037	.222
z_{52}	1	.042	.042

*Percentage of the 1978 total resources (X_i/total resources)

D. Investment Services

If DDC is to remain viable it must continually improve its capabilities to meet the forecast for increased demands predicted by the 10 Year Requirements and Planning Study. This requires the use of labor resources to improve its performance capabilities through development projects.

The approach to formulating the investment services constraints is analogous to the approach for basic services. Two goal criteria are considered:

- goal criteria (a_j):

  a_6 = Proportion of the total service program desired for investment services (15%)

  a_7 = Number of man-years available for investment services (68)

D.1 Percentage of the Total Program that is Considered Investment

Using the same approach as equation (5), equation (7) can be written:

$$\sum_{i=31}^{34} y_i + .20\,(y_{41} + y_{42}) + .60\,y_{43} + .50\,y_{44} + y_{45}$$

$$- a_6 \left(\sum_{i=11}^{26} x_i + \sum_{i=31}^{45} y_i + y_{52} \right) + d_6^- - d_6^+ = 0 \qquad (7)$$

D.2 Formulation of an "Effective" Investment Program Constraint

To apportion the investment resources according to effectiveness weights the constraint for an effective investment program is derived in the same fashion as formula (6). Both new and established investment programs are weighted for their contributions to an effective program using the same scale used for the basic program (see Appendix C, Table C-3). The main determinants of the effectiveness coefficients are:

responsiveness to organizational goals and the willingness of management to commit resources.

Table 3-5 provides the data for the constraint:

$$\sum_{i=31}^{34} E_i y_i + .20\,(E_{41} y_{41} + E_{42} y_{42}) + .60\, E_{43} y_{43} +$$

$$.50\, E_{44} y_{44} + E_{45} y_{45} = a_7 \qquad (8)$$

where E_i represents a measure of probable effectiveness calculated for each investment project. The values that have been calculated in concert with management are shown in Table 3-5. The values of e_1 and e_2 are calculated in Appendix C, Table C-3.

E. Target Levels for Individual Programs

It is necessary to set target levels for the distribution of available resources to specific projects. If there were no individual targets, the model would call only for the most effective programs (i.e. those with high values of E_i). these constraints will provide resources to many of the projects that received low E_i scores but are essential to projects with high scores. For example, x_{11} (R&T WUDB Input) is needed to provide x_{12} (R&T WUDB Output) but x_{11}'s E_i score is too low to demand required resources.

The goal criteria for these constraints can be stated as a factor of workload estimates, percentages of the total resources which should be allotted to each project or as simply the actual number of man-years desired. Since the actual number is provided in the 1978 Program/Budget, the actual number is used.

TABLE 3-5. PROBABLE EFFECTIVENESS COEFFICIENTS (INVESTMENT PROGRAM)

Variable	e_1 Effectiveness factor scores	e_2 Management's willingness to committ resources	$E_i = \pi\, e_1\, e_2$
y_{31}	5	0	0
y_{32}	6	.007	.042
y_{33}	5	.011	.055
y_{34}	2	.002	.004
y_{41}	4	.011	.044
y_{42}	4	.015	.06
y_{43}	4	.042	.168
y_{44}	6	.037	.222
y_{45}	5	.061	.305

- goal criteria (a_j):

a_8	=	Target level for the number of man-years alloted to	x_{11} (13)
a_9	=	"	x_{12} (13)
a_{10}	=	"	x_{13} (1)
a_{11}	=	"	x_{15} (2)
a_{12}	=	"	x_{16} (1)
a_{13}	=	"	x_{17} (4)
a_{14}	=	"	x_{18} (2)
a_{15}	=	"	x_{19} (15)
a_{16}	=	"	x_{191}(2)
a_{17}	=	"	x_{192}(2)
a_{18}	=	"	x_{21} (91)
a_{19}	=	"	x_{22} (10)
a_{20}	=	"	x_{23} (62)
a_{21}	=	"	x_{24} (7)
a_{22}	=	"	x_{25} (1)
a_{23}	=	"	x_{26} (23)
a_{24}	=	"	y_{31} (0)
a_{25}	=	"	y_{32} (3)
a_{26}	=	"	y_{33} (5)
a_{27}	=	"	y_{34} (1)
a_{28}	=	"	y_{41} (5)
a_{29}	=	"	y_{42} (7)
a_{30}	=	"	y_{43} (19)
a_{31}	=	"	y_{44} (17)
a_{32}	=	"	y_{45} (25)
a_{33}	=	"	z_{51} (80)
a_{34}	=	"	z_{511}(4)
a_{35}	=	"	z_{52} (19)
a_{36}	=	"	z_{53} (5)
a_{37}	=	"	z_{60} (15)

The general formulae for this constraint are:

$$x_{i-11}^{26} + (d_i^- - d_i^+) = a_{j=8}^{23} \qquad (9)$$

$$y_{i=31}^{45} + (d_j^- - d_j^+) = a_{j=24}^{32} \qquad (10)$$

$$z_{i=51}^{60} + (d_i^- - d_i^+) = a_{j=33}^{37} \qquad (11)$$

F. Program Responsiveness to Organizational Goals and User Needs

For the overall program to be responsive to organizational goals, criteria must be set to define a balanced program. These criteria should describe all service qualities which DDC regards as valid for a well-balanced overall program, regardless of whether or not there are projects proposed to meet all the goals.

The following constraints are designed to provide at least minimum program responsiveness to all known program requirements. If not met, they will identify gaps in the program. This formulation assumes that if the desired labor resources are applied to program requirements that productive output will follow to satisfy the requirements. This means that labor is considered the main ingredient to a successful program.

Since organizational values change over a period of time, the goal criteria considered here must be reevaluated in each planning period.

For the DDC Environment, three aspects of program responsiveness are considered.

- The classes of users being served
- Functional goal requirements
- Responsiveness to user needs

F.1 Classes of Users Being Served

The classes of users for which management has expressed particular concern are:

- RDT&E managers
- RDT&E scientists and engineers
- Libraries and other intermediary information agencies

- goal criteria (a_j):

a_{38} = Desired ratio of (support for RDT&E managers) to (support for scientists and engineers) (1:7)

a_{39}, a_{40}, a_{41} = The workload that must be processed by project x_{23} (Technical Report Request Distribution) to provide service to libraries. Management has specified three criteria for this constraint which will be explained in F.1.2.

F.1.1 Ratio of Service to Managers/Scientists and Engineers

The interest in providing services to support RDT&E managers is significant among DDC's Administrative Constituents. It has also been noted in the 10 year requirements and planning study that support to managers, other than the Office of the Director, Defense Research and Engineering is minimal. However, it is necessary to recognize that the bulk of DDC's responsibilities is related to the technical report program which is principally useful to scientists and engineers. Goal criteria a_{38} is a desired service ratio between the two main user classes. It should be noted that the 1978 Program/Budget identifies no investment effort specifically to improve services for managers. Therefore, the model will attempt to compensate for that deficiency in meeting this criterion by allotting more resources to the basic project designed for managers that has the highest E_i value - namely x_{12}, the R&T Work Unit Data Base.

The formula for a_{38} can be derived from the data in Appendix C, Table C-3 as follows:

$$\sum\left[(x_{11} + x_{12}) + (x_{15} + x_{16}) + (x_{17} + x_{18})\right] / \sum\left[x_{13} + \sum_{i=19}^{192} x_i + \sum_{i=22}^{26} x_i + \sum_{i=31}^{33} y_i\right] + d_{38}^{-} - d_{38}^{+} = a_{38} \quad (12)$$

where x_{11}, x_{12}, x_{15}, x_{16}, x_{17} and x_{18} are projects for RDT&E managers and the specified projects, x_i and y_i are projects for scientists and engineers.

F.1.2 Service to Libraries

One of the most important determinants of DDC's performance with respect to serving libraries is its ability to process technical report requests, project x_{23}. Using the workload estimates of the 1978 Program Budget, it is possible to compute the productivity of a man-year of effort for this activity as follows:

$$\frac{To_{23}}{My_{23}} = P_{23} \quad (13)$$

where:

To_{23} = Total units of output for project 2.3 in a planning period (366,000)

My_{23} = Total man-years input to project 2.3 (62)

P_{23} = Productivity of a man-year of effort in project 2.3 (5903)

Then the general constraint can be written:

$$P_{23}\, x_{23} + d_{39}^{-} - d_{39}^{+} = a_{39} \quad (14)$$

where a_{39} is the number of technical reports x_{23} must be able to process to serve 97% of the estimated requests for 1978. 97% represents the proportion of reports which are distributed to non-library users.

To specify that management desires to be able to process from 3% in 10% additional requests to serve libraries, the constraints

are written:

$$P_{23}\, x_{23} + d_{40}^{-} - d_{40}^{+} = a_{40} \tag{15}$$

$$P_{23}\, x_{23} + d_{41}^{-} - d_{41}^{+} = a_{41} \tag{16}$$

where a_{40} specifies a desired capability of at least 3% over that needed to serve prime users directly, in order to serve library requests, and a_{41} specifies a desired additional capability of at most 10%.

The goal criteria for equations (14), (15) and (16) were calculated from the 1978 Program/Budget data. They are shown in Table 6.

TABLE 3-6. GOAL CRITERIA FOR SERVICE TO LIBRARIES

a_j	Desired units of output
a_{39}	355,020
a_{40}	365,671 (3% a_{39} + a_{39})
a_{41}	390,522 (10% a_{39} + a_{39})

F.2 Responsiveness to Organizational Goals of DoD Administrators

There is tremendous potential for refining the sensitivity of the model using the type of constraint described in this section. It would require careful consideration of the goal criteria by DDC, and possibly a restructuring or finer breakdown of program projects than that shown in the 1978 Program/Budget.

Table 3-1 indicated a goal structure for decision analysis that was inferred from the goals survey of DoD administrators. It indicated that four information service functions should be provided by DDC. Goal criteria and definitions of the relationships between projects and organizational goals have been provided by management in the form of desired percentages of the basic and investment program projects that should be devoted to the four organizational goals.

- goal criteria (a_j):

a_{42} = Desired percentage of the basic program providing access to information as opposed to documents (18%)

a_{43} = Desired percentage of the investment program devoted to improving access to information as opposed to documents (25%)

a_{44} = Desired percentage of the basic program providing access to DDC held documents (52%)

a_{45} = Desired percentage of the investment program devoted to improving access to DDC held documents (25%)

a_{46} = Desired percentage of the basic program providing remote access to documents and information (10%)

a_{47} = Desired percentage of the investment program devoted to improving remote access to documents and information (15%)

a_{48} = Desired percentage of the basic program promoting the use of information products and services (5%)

Constraints for the model can be expressed as follows:

F.2.1 Desired Proportion of the Program Concerned with Providing Access to Information as Opposed to Documents

$$\text{Basic Program: } \left[\prod_{i=1}^{26} I_{42i} x_i + \prod_{i=31}^{45} I_{42i} y_i + \prod_{i=51}^{60} I_{42i} z_i / S \right] +$$

$$d^-_{42} - d^+_{42} = a_{42} \qquad (17)$$

where:

I_{42i} = Identity coefficients which indicate management's description of the i^{th} project with regard to its fulfilling organizational goal criterion a_{42}. Zero indicates it does not serve this function, 1 indicates it does. Values less than 1 indicate the percentage of the program contributing to goal a_{42} (Values for I_{42i} are shown in Table 3-7).

S = The total service program:

$$\sum_{i=11}^{26} x_i + \sum_{i=31}^{45} y_i + y_{52} \tag{18}$$

Investment program:

$$\left[\prod_{i=11}^{26} I_{43i}x_i + \prod_{i=31}^{45} I_{43i}y_i + \prod_{i=51}^{60} I_{43i}z_i \;/\; S\right] +$$

$$d^-_{43} - d^+_{43} = a_{43} \tag{19}$$

where: S = equation (18)

I_{43i} = Identity coefficients which indicate the projects associated with goal criterion a_{43} (Table 3-7).

F.2.2 Desired Proportion of the Program Concerned with Providing Access to Documents

Basic Program:

$$\left[\prod_{i=11}^{26} I_{44i}\, x_i + \prod_{i=31}^{45} I_{44i}\, y_i + \prod_{i=51}^{60} I_{44i}\, z_i \;/\; S\right] +$$

$$d^-_{44} - d^+_{44} = a_{44} \tag{20}$$

TABLE 3-7. VALUES OF I_{42i} - I_{50i}

	I_{42i}	I_{43i}	I_{44i}	I_{45i}	I_{46i}	I_{47i}	I_{48i}	I_{49i}	I_{50i}
x_{11}	1	0	0	0	0	0	0	0	0
x_{12}	1	0	0	0	0	0	0	0	0
x_{13}	1	0	0	0	0	0	0	0	0
x_{15}	1	0	0	0	0	0	0	0	0
x_{16}	1	0	0	0	0	0	0	0	0
x_{17}	1	0	0	0	0	0	0	0	0
x_{18}	1	0	0	0	0	0	0	0	0
x_{19}	1	0	1	0	0	0	0	1	0
x_{191}	1	0	1	0	0	0	0	1	0
x_{192}	1	0	1	0	0	0	0	1	0
x_{21}	0	0	1	0	.044*	0	0	0	1
x_{22}	0	0	1	0	0	0	0	0	0
x_{23}	0	0	1	0	0	0	0	0	0
x_{24}	0	0	1	0	0	0	0	0	0
x_{25}	0	0	0	0	0	0	0	0	0
x_{26}	0	0	1	0	0	0	0	0	0
y_{31}	0	1	0	1	0	0	0	0	0
y_{32}	0	1	0	0	0	1	0	0	0
y_{33}	0	1	0	0	0	0	0	0	0
y_{34}	0	1	0	1	0	0	0	0	0
y_{41}	.80	.20	0	0	0	0	0	0	0
y_{42}	0	0	.80	.20	0	0	0	0	0
y_{43}	.40	.60	0	0	0	0	0	0	0
y_{44}	.50	.50	.50	.50	.50	0	0	1	0
y_{45}	0	1	0	1	0	0	0	0	0
z_{51}	0	0	0	0	0	0	0	0	0
z_{511}	0	0	1	0	0	0	1	0	0
z_{52}	1	0	0	0	0	0	0	0	0
z_{53}	0	0	0	0	0	0	0	0	0
z_{60}	0	0	0	0	0	0	0	0	0
Desired Percentages	18%	25%	.52	.25	.10	.15	.05	.20	.20

*This value represents 4 of the 91 staff positions in project x_{21}.

where: I_{44i} = projects associated with goal criterion a_{44} (Table 3-7)

S = equation (18)

Investment Program:

$$\left[\prod_{i=11}^{26} I_{45i}\, x_i + \prod_{i=31}^{46} I_{45i}\, y_i + \prod_{i=57}^{60} I_{45i}\, z_i \;/\; S \right] +$$

$$d^-_{45} - d^+_{45} = a_{45} \qquad (21)$$

where: I_{45i} = is indicated in Table 3-7 and

S = equation (18)

F.2.3 Desired Proportion of the Program Concerned with Providing Remote Access to Documents and Information

Basic Program:

$$\left[\prod_{i=11}^{26} I_{46i}\, x_i + \prod_{i=31}^{45} I_{46i}\, y_i + \prod_{i-51}^{60} I_{46i}\, z_i \;/\; S \right] +$$

$$d^-_{46} - d^+_{46} = a_{46} \qquad (22)$$

where: I_{46i} = is indicated in Table 3-7 and

S = equation (18)

Investment Program:

$$\left[\prod_{i=11}^{26} I_{47i}\, x_i + \prod_{i=31}^{45} I_{47i}\, y_i + \prod_{i=51}^{60} I_{47i}\, z_i \;/\; S \right] + d^-_{47} - d^+_{47} = a_{47} \qquad (23)$$

where: I_{47i} = is indicated in Table 3-7 and

S = equation (18)

F.2.4 Desired Proportion of the Program Concerned with Promoting Information Products and Services

Basic Program:

$$\left[\prod_{i=11}^{26} I_{48i}x_i + \prod_{i=31}^{45} I_{48i}y_i + \prod_{i=51}^{60} I_{48i}z_i \quad / S\right] + d_{48}^- - d_{48}^+ = a_{48} \quad (24)$$

where: I_{48i} = is indicated in Table 3-7 and

S = equation (18)

F.3 Program Responsiveness to User Needs

Two goal criteria were identified by management for consideration.

- goal criteria (a_j):

a_{49} = Desired percentage of the program resources devoted to projects that provide timely service, (i.e. 24 hour turn-around). (20%)

a_{50} = Desired percentage of resources devoted to the function of conserving DoD RDT&E Technical reports. (20%)

F.3.1 Timeliness Goal Criterion

Using the same approach as section F.2, the constraint can be written:

$$\left[\prod_{i=11}^{26} I_{49i}y_i + \prod_{i=31}^{45} I_{49i}y_i + \prod_{i=51}^{60} I_{49i}z_i \quad / S\right] + d_{49}^- - d_{49}^+ = a_{49} \quad (25)$$

where: I_{49i} = is indicated in Table 3-7 and

S = equation (18)

F.3.2 Conservation of DoD RDT&E Technical Reports

Continuing the approach used in F.3.1:

$$\left[\prod_{i=11}^{26} I_{50i}^{y_i} + \prod_{i=31}^{45} I_{50i}^{y_i} + \prod_{i=51}^{60} I_{50i}^{z_i} \;/\; S \right] + d_{50}^{-} - d_{50}^{+} = a_{50} \qquad (26)$$

where: I_{50i} = is indicated in Table 3-7 and

S = equation (18)

DEVELOPMENT OF THE OBJECTIVE FUNCTION

The objective function specifies the priorities for minimizing the positive (d_j^+) and the negative (d_j^-) deviations from the 50 goal criteria (a_j). These priorities are assigned by management. They specify the importance attached to each of the goals by DDC.

First, the preemptive priority factors (P_k) must be assigned to the deviational variables. Second, if necessary, differential weights can be assigned to deviational variables at the same priority level.

Table 3-8 is the initial priority ordering as structured for the first test run of the model that is described in Section IV.

CONCLUSION

The temptation is strong to formulate additional constraints that express interesting relationships among the variables. Indeed, additional constraints would add to the model's sensitivity. However, it must be considered that they would also add significantly to the complexity of the model. On balance, a more complex model than the formulation presented in this report would appear to be counter productive until such time as those who will operate it at DDC have mastered the goal programming technique and can actively participate in expanding the basic formulation.

TABLE 3-3. INITIAL OBJECTIVE FUNCTION VALUES P_k*

Goal Criteria (a_i)	Initial run d^-	Initial run d^+
A. Total Staff		
a_1 (491)	P_2	0
a_2 (454)	P_1	P_1
B. Total Cost		
a_3 (0)	0	P_7
C. Basic Services		
a_4 (85%)	P_4	-
a_5 (363)	P_5	0
D. Investment Services		
a_6 (15%)	P_4	-
a_7 (68)	P_5	0
E. Target Levels for Individual Programs in man-years		
a_8 (13)	P_6	-
a_9 (13)	P_6	-
a_{10} (1)	P_6	-
a_{11} (2)	P_6	-
a_{12} (1)	P_6	-
a_{13} (4)	P_6	-
a_{14} (2)	P_6	-
a_{15} (15)	P_6	-
a_{16} (2)	P_6	-
a_{17} (2)	P_6	-
a_{18} (91)	P_6	-
a_{19} (10)	P_6	-
a_{20} (62)	P_6	-
a_{21} (7)	P_6	-
a_{22} (1)	P_6	-
a_{23} (23)	P_6	-
a_{24} (0)	P_6	-
a_{25} (3)	P_6	-
a_{26} (5)	P_6	-
a_{27} (1)	P_6	-
a_{28} (5)	P_6	-
a_{29} (7)	P_6	-
a_{30} (19)	P_6	-
a_{31} (17)	P_6	-
a_{32} (25)	P_6	-
a_{33} (80)	P_6	-
a_{34} (4)	P_6	-
a_{35} (19)	P_6	-
a_{36} (5)	P_6	-
a_{37} (15)	P_6	-

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TABLE 3-8. INITIAL OBJECTIVE FUNCTION VALUES P_k* (cont'd)

a_j	Initial run d^-	Initial run d^+
F. Distribution by Organizational Goals and User Needs		
F.1.1 Managers vs. Scientists and Engineers		
a_{38} (1:7)	P_3	P_3
F.1.2 Libraries (workload)		
a_{39} (355,020)	P_3	-
a_{40} (365,671	P_3	-
a_{41} (390,000	P_3	0
F.2 Functional Goals		
a_{42} (18%)	P_3	P_3
a_{43} (25%)	P_3	P_3
a_{44} (52%)	P_3	P_3
a_{45} (25%)	P_3	P_3
a_{46} (10%)	P_3	P_3
a_{47} (15%)	P_3	P_3
a_{48} (5%)	P_3	P_3
F.3 Responsiveness to Users		
a_{49} (20%)	P_3	P_3
a_{50} (20%)	P_3	P_3

*P_k is the priority order assigned to indicate the importance of minimizing the respective deviations from the goal criteria, a_j. 0 indicates an impractical solution not to be considered in the model whereas a blank indicates the deviational variable is in the model, but not in the objective function.

SECTION IV. RESULTS AND ANALYSIS

As indicated in the Introduction, the objective of this study has been to present a pragmatic goal programming model applicable to the DDC decision environment and test its application potential in policy analysis with respect to resource allocation and project evaluation decision making.

The model is presented in the preceding Section. This section presents the test results and analysis.

4.1 TEST METHOD

The application potential of the goal programming model is principally a question of whether the model produces useful information for decision-making by DDC managers and administrators. It is appropriate, then, to test the model by producing solutions to a decision problems, analyzing the results and, in collaboration with DDC management, examining in what ways the information produced by the model is actually useful.

Three types of information are provided in goal programming model solutions:

(1) Identification of the optimum resource allocation scheme. It is optimum in the sense that the given solution enables the decision-maker to attain his goals as nearly as possible within the stated goal criteria and priority structure.

(2) The degree of goal attainment provided by a proposed program design.

(3) The relative degree of goal attainment provided by alternative goal priority structures.

The following test runs demonstrate the use of this information for decision analysis of resource allocation and program evaluation problems at DDC.[1]

In addition, because this is a testing procedure, the discussion of the test results is equally concerned with examining the completeness and sensitivity of the model. These characteristics determine the model's ability to reflect the real problem.

4.2 DISCUSSION FORMAT

The discussion format is structured to demonstrate the manner in which goal programming is used for decision analysis. Each run consists of four steps:

(1) Consideration of the relationship of the run to the basic decision problem. The initial run establishes the rationale for the overall approach to analyzing the problem. Subsequent runs are based on the decision-maker's review of his priorities and judgement in view of model solutions.

(2) Definition of goal criteria and priorities for the run.

(3) Computation of the solution.[2]

(4) Analysis of the solution.

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[1] Insofar as the technical data and goal criteria are quantitatively accurate, these solutions also provide reliable guidance for evaluating the 1978 Program/Budget against the stated administrative goals. However, such use of these results is contingent upon careful review of the input data by operating managers. The data used for the study was supplied by DDC primarily to test the applicability of the goal programming methodology.

[2] The computer program used to calculate problem solutions is described in Appendix D.

4.3 RUN 1

The initial run is directed toward examining the use of the goal programming model for evaluating an overall program plan in terms of organizational goal criteria. DDC's 1978 Program/Budget plan is used as the test program.

4.3.1 Relationship of the First Run to the Decision Problem

The goal criteria in the model represent six concepts:

A. Total staff constraint
B. Total cost constraint
C. Basic services goal
D. Investment services goal
E. Target levels for manning the projects in the proposed program
F. Balanced distribution of labor resources according to organizational and user need goal criteria

In the first run the model was used to determine what would happen to the proposed program (item E) if the goals to achieve a well balanced program (item F) and the service goals (items C and D) were considered more important than carrying out the proposed project plan at the levels of effort anticipated in the 1978 Program/Budget.

In effect, this scheme evaluates the proposed program in terms of the goal criteria. Only if the proposed program were in balance with all other goals could the solution match the 1978 Program/Budget labor allocation plan.

Specifically, in this run the model treats all the proposed projects as equivalent alternatives by which DDC may serve its organizational mission. Using the higher order goal criteria (i.e. higher than the priority given to the administrator's commitment to its proposed program) as a basis for choosing among the project, the model tends to allocate resources to projects with high scores on effectiveness (goal criteria a_5 and a_7) which also contribute to the attainment of the organizational goals (goal criteria a_{38} to a_{50}). Projects with low evaluation ratings in the model receive little or no resources.

As a result, it is valid to conclude that for the projects receiving no resources in the solution, insufficient justification for carrying out these projects has been provided, by management, in the model.

For the decision-maker this means that he must review his basis for setting the resource targets in the program plan (Item E). If sufficient justification cannot be found for those projects which the model has not supported, then the unjustified projects should be discontinued. The freed resources (i.e. staff positions) should be reallocated to a project more in the line with the organization's goals. However, it is possible that there are implied organizational goals represented in the stated program plan, for example maintaining "staff stability". If so, additional program justification (i.e. "goals") determined in this manner should be documented and possibly factored into the basic model. At least, it should be noted in the Annual Program/Budget justification.

Of equal interest to the decision maker, the goal programming technique of decision analysis provides him with an opportunity to review this judgement of the goal priorities in view of the solution. This will lead to further runs to consider policy alternatives that might produce a more satisfactory degree of goal attainment, including a more satisfactory allocation of resources solution. In the process, *the decision maker will arrive at a clearer understanding of his* priority structure than he had before using the model.

For this study, a matter of special interest to DDC was introduced into the decision problem in order that DDC would have a meaningful basis for judging the model's usefulness. In the 1978 Program/Budget it was planned to commit 4 permanent staff positions to manning remote computer data base access centers at Boston and Los Angeles as part of DDC's basic service program (represented by goal criteria a_{16} and a_{17}). This represented a transfer of the effort from a developmental project to a basic program.

In practice, the decision-maker would want the model to help determine how such new projects fit into the overall program and how

they relate to the stated organizational goals. He is able to do so with the use of the model because the quantitative properties that relate all projects to the organizational goals have been defined in the basic model. The numerical data relative to the new projects have been supplied for this study by DDC and are represented in the data tables of Section III in association with project symbols X_{191} and X_{192}.

In the initial run, the priority to commit adequate labor resources to the new projects X_{191} and X_{192} is put at level six (P_6) along with all other projects such that all proposed projects would be evaluated on an equal basis, subject to the higher priority organizational and service goal criteria specified in the input data (P_3 and P_5).

One other characteristic of the initial run which should be noted is that the goal to minimize costs has been placed at the lowest level. This is done to treat the program evaluation question initially on the merits of technical criteria only. When the cost criteron is targeted at zero dollars and made the lowest goal as it is in this run, the effect is that the model calculates the total projected cost of its optimal solution as positive slack (d_7^+). In other words, the value of d_7^+ is the cost of this solution. Thus, one more useful item of information for decision-making is supplied.

4.3.2 Goal Criteria and Priorities for Run 1

Table 4-1 illustrates the goal criteria and priorities for the initial run. These data are used to construct the objective function which specifies the importance attached to each of the goals by management for the run.

The first priority (P_1) specifies that the total staff should be 454 as targeted in the 1978 budget (a_2). The second priority (P_2) specifies that 491 staff positions could be supported by using outside contract services to augment the in-house staff (a_1). The goal of priority three (P_3) is that the labor resources should be apportioned among projects in a way that they meet criteria for a well balanced program according to organizational goals and user needs (a_{38} through a_{50}). Priority four (P_4) is the goal to have a program which is 85% devoted to providing basic services and at least 15% devoted to programs

TABLE 4-1. INITIAL OBJECTIVE FUNCTION VALUES P_k*

Goal Criteria (a_i)**	Run 1	
	d^-	d^+
A. Total Staff		
a_1 (491)	P_2	0
a_2 (454)	P_1	P_1
B. Total Cost		
a_3 (0)	0	P_7
C. Basic Services		
a_4 (85%)	P_4	-
a_5 (363)	P_5	0
D. Investment Services		
a_6 (15%)	P_4	-
a_7 (68)	P_5	0
E. Target Levels for Individual Programs in man-years		
a_8 (13)	P_6	-
a_9 (13)	P_6	-
a_{10} (1)	P_6	-
a_{11} (2)	P_6	-
a_{12} (1)	P_6	-
a_{13} (4)	P_6	-
a_{14} (2)	P_6	-
a_{15} (15)	P_6	-
a_{16} (2)	P_6	-
a_{17} (2)	P_6	-
a_{18} (91)	P_6	-
a_{19} (10)	P_6	-
a_{20} (62)	P_6	-
a_{21} (7)	P_6	-
a_{22} (1)	P_6	-
a_{23} (23)	P_6	-
a_{24} (0)	P_6	-
a_{25} (3)	P_6	-
a_{26} (5)	P_6	-
a_{27} (1)	P_6	-
a_{28} (5)	P_6	-
a_{29} (7)	P_6	-
a_{30} (19)	P_6	-
a_{31} (17)	P_6	-
a_{32} (25)	P_6	-
a_{33} (80)	P_6	-
a_{34} (4)	P_6	-
a_{35} (19)	P_6	-
a_{36} (5)	P_6	-
a_{37} (15)	P_6	-

AAI

TABLE 4-1. INITIAL OBJECTIVE FUNCTION VALUES P_k* (cont'd)

Goal Criteria a_{ij} **	Run 1	
	d^-	d^+
F. Distribution by Organizational Goals and User Needs		
F.1.1 Managers vs. Scientists and Engineers		
a_{38} (1:7)	P_3	P_3
F.1.2 Libraries (workload)		
a_{39} (355,020)	P_3	-
a_{40} (365,671	P_3	-
a_{41} (390,000	P_3	0
F.2 Functional Goals		
a_{42} (18%)	P_3	P_3
a_{43} (25%)	P_3	P_3
a_{44} (52%)	P_3	P_3
a_{45} (25%)	P_3	P_3
a_{46} (10%)	P_3	P_3
a_{47} (15%)	P_3	P_3
a_{48} (5%)	P_3	P_3
F.3 Responsiveness to Users		
a_{49} (20%)	P_3	P_3
a_{50} (20%)	P_3	P_3

*P_k is the priority order assigned to indicate the importance of minimizing the respective deviations from the goal criteria, a_j. P_1 has the highest priority.

0 indicates an impractical solution not to be considered in the model whereas a blank indicates the deviational variable as the model, but not in the objective function.

** The numerial values for a_j are explained in Section III with the description of the basic mode.

considered to be "investments" for developing future capabilities (a_4 and a_6).

Priority five (P_5) is the goal to distribute the available labor resources to projects according to their relative effectiveness (a_5 and a_7). The goal of priority six (P_6) is to provide the specified labor resources shown in the 1978 Program/Budget. Priority seven (P_7) is the cost goal which is set at zero to minimize costs and calculate the projected cost of the opitmum solution.

4.3.3 Solution (Run 1)

The optimum solution calculated for the first run is provided in Tables 4-2, 4-3, and 4-4. For demonstration purposes, the tables illustrate the computer print-outs.

The slack analysis (Table 4-2) indicates how close the optimum solution comes to meeting the 50 specified goal criteria in the model. Positive slack (POS-SLK) indicates by how much the solution exceeded a criterion and negative slack (NEG-SLK) indicates by how much the solution failed to meet a criterion. The row numbers (a_j) correspond to the goal criteria numbers of the basic model described in Section III.

The variable analysis (Table 4-3) designates the labor resources the model has allocated to the proposed projects.

The analysis of the objective (Table 4-4) indicates the degree of goal attainment represented in the solution.

4.3.4 Analysis of the Solution (Run 1)

The optimum solution indicates in Table 4-3 that only 12 of the thirty projects should receive labor resources if the goal structure and the model inputs are accurate. It should be noted that projects X_{191} and X_{192} to support the remote access computer terminals are not among the projects in the solution. However, this solution is the "best" possible to attain the goals as closely as possible within the stated criteria.

With respect to the projects X_{191} and X_{192} it would appear that based on the criteria provided in the model that there are more

TABLE 4-2. SLACK ANALYSIS (RUN 1)

Project Codes	ROW (aj.)	AVAILABLE	POS-SLK	NEG-SLK
	1	491	0	37
	2	454	0	0
	3	0	9268	0
	4	0	0	75
	5	363	0	278
	6	0	75	0
	7	68	0	46
11	8	13	0	13
12	9	13	4	0
13	10	1	6	0
15	11	2	0	2
16	12	1	0	1
17	13	4	0	4
18	14	2	0	2
19	15	15	0	15
191	16	2	0	2
192	17	2	0	2
21	18	91	0	31
22	19	10	0	10
23	20	62	4	0
24	21	7	0	7
25	22	1	0	1
26	23	23	0	23
31	24	0	0	0
32	25	3	42	0
33	26	5	0	5
34	27	1	0	1
41	28	5	0	5
42	29	7	0	7
43	30	19	0	19
44	31	17	43	0
45	32	25	20	0
51	33	80	49	0
511	34	4	0	0
52	35	19	0	19
53	36	5	0	0
60	37	15	0	0
	38	0	0	0
	39	355020	35504	0
	40	365671	24851	0
	41	390522	0	0
	42	0	0	0
	43	0	45	0
	44	0	0	0
	45	0	0	0
	46	0	0	0
	47	0	0	0
	48	0	0	11
	49	0	0	0
	50	0	0	0

TABLE 4-3. VARIABLE ANALYSIS (RUN 1)

Symbol	Name	Variable No.	Amount
X_{23}	Tech Report Request Distr	13	67
X_{19}	RDT&E On-Line Terminal	8	1
X_{32}	Integrated R&D Info Sys	18	46
X_{45}	DDC Sys Redesign and Imple	25	46
X_{51}	Management and Admin	26	130
X_{511}	4 People for Promotion & Markg	27	4
X_{53}	STINFO Central Registry	29	5
X_{60}	Support of Non-DDC Act	30	15
X_{12}	R&T WUDB Output	2	17
X_{13}	STINFO S/R Data Bank	3	8
X_{44}	RDT&E On-Line System	24	61
X_{21}	Technical Report Input	11	61

TABLE 4-4. ANALYSIS OF THE OBJECTIVE (RUN 1)

PRIORITY	UNDER-ACHIEVEMENT
7	9278
6	169
5	324
4	75
3	59
2	37
1	0
ARTIFICIAL	0

important priorities to serve before any further expansion of the on-line system is undertaken.

This solution provides interesting information about the model because it identifies the projects that are clearly related to the organizational goals. However, the distribution of resources it calls for may be impossible to achieve in reality. In fact, upon consideration of this solution, the decision-maker collaborating on the evaluation determined that regardless of whether the stated criteria were valid, such a solution would not be feasible and even at the expense of organizational goals a more satisfactory outcome had to be sought.

Other information provided by the solution indicates that for the seven goal priorities only the first goal was fully attained (i.e. use 454 man-years), and the cost (priority seven) is approximately \$9,268,000.[3] The cost exceeds the projected labor budget in the 1978 Program/Budget (i.e. \$8,778,000) by 5.58%.

The excess cost of 5.38% was of some concern but not enough to make cost a higher priority constraint. On the other hand, the low degree of goal attainment raises significant questions about the consistency of the goal structure and criteria expressed in the model.

For example, it was not possible to fully achieve the balanced program goal specified as priority three. This was a result of inconsistency among the criteria within the third priority as no conflict with a higher goal was indicated in the solution. In addition, in order to maximize the degree of achievement represented in the third priority it was necessary for the model to allocate more than 15% of the total resources to investment programs. This can be seen in Table 4-2 with respect to rows a_4 and a_6 where the basic program goal (85%) is underachieved by approximately 75 units, and the investment program goal (15%) is overachieved by approximately 75 units. This undicates simply that the goal criteria to distribute the labor resources according to organizational goals, including user needs and specified

[3] See Table 4-4. It should be noted that the algorithm used to compute a solution may assign an "artificial" priority to the goal structure in order to obtain a first iteration solution basis but this does not change the net outcome of the model.

functions (a_{38} through a_{50}) call for more than 15% of the total program in the investment aspects.

These results suggest a number of questions for the analyst and decision-maker to consider. Are the goal criteria, especially the organizational goals (a_{38} through a_{50}) and service goals (a_4 and a_6) reasonable? If so, have the properties of the proposed projects been accurately characterized in relationship to these goals. Re-examination of the data applicable to projects X_{191} and X_{192}, for instance indicates that they are characterized as "basic" projects. The model solution indicates that the program is deficient in its investment aspects. Perhaps projects X_{191} and X_{192} are representative of the type of effort DDC intends to pursue as investment projects. Certainly, they represent a significant improvement in DDC's manner of providing information services. If so, they should be re-coded as investment projects, in which case it is more likely the model would allocate resources to them.

4.3.5 Implications of the Results

The main result of the initial run is to underscore the complexity of DDC's decision environment. The operating program is forced to respond to multiple, competing criteria. Taken alone, each of the stated goal criteria appears reasonable. Together they are inconsistent and in conflict. The model helps identify where the conflicts exist.

The guides for decision making suggest that more planning emphasis should be placed on investment projects, particularly investment projects to improve access to information; and, that appropriate goals must be stated to justify the projects that were not represented in this solution, if they are not to be discontinued.

4.4 RUN 2

Emphasis in the second run is placed on examining the use of the model to determine the degree of goal attainment provided by a specified program of projects.

4.4.1 Relationship of the Second Run to the Decision Problem

It was evident from the results of the first run that the 1978 Program/Budget does not conform to the organizational goals. Nevertheless, there appears to be a certain degree of validity to both the program's labor allocation targets and the organizational goal criteria.

For the second run it was assumed that the organizational and user need goal criteria (a_{38} through a_{50}) and the service goals (a_4 through a_7) represent evaluation criteria which DDC's administrative and user constituences might consider desirable characteristics of DDC's information services. The program target levels (a_8 through a_{37}) represent the results of DDC's consideration of all the practical constraints and limitations of developing an operational program of products and services.

Furthermore, the administrator determined that certain projects were essential to DDC's operation, even if they could not be clearly related to the organizational goal structure. These projects were designated higher priority items for Run 2 than the organizational goal priorities.

Using this strategy of formulating the problem, the decision-maker can analyze the effect of the specified program on the organizational goals. Moreover, the model will identify the goal areas in which the program is deficient and those in which it is strong. Such information, particularly where the program is deficient in relation to the goals, is useful for planning new projects for subsequent budget years. This aspect is also useful for discussing the nature of the information program with users for discussing the nature of the information program with users and administrative constraints interested in the DDC program.

4.4.2 Goal Criteria and Priorities for Run 2

Table 4-5 illustrates the goal criteria and priorities for run 2 in comparison with run 1. The criteria (a_j) are unchanged from the initial run. However, the priority structure is different.

TABLE 4-5. RUN 2 OBJECTIVE FUNCTION VALUES P_k *

Goal Criteria (a_i)**	Run 1		Run 2	
	d^-	d^+	d^-	d^+
A. Total Staff				
a_1 (491)	P_2	0	-	P_2
a_2 (454)	P_1	P_1	P_1	-
B. Total Cost				
a_3 (0)	0	P_7	0	P_8
C. Basic Services				
a_4 (85%)	P_4	-	P_4	P_4
a_5 (363)	P_5	0	P_6	0
D. Investment Services				
a_6 (15%)	P_4	-	5	P_5
a_7 (68)	P_5	0	P_6	0
E. Target Levels for Individual Programs in man-years				
a_8 (13)	P_6	-	P_3	-
a_9 (13)	P_6	-	P_3	-
a_{10} (1)	P_6	-	P_3	-
a_{11} (2)	P_6	-	P_3	-
a_{12} (1)	P_6	-	P_3	-
a_{13} (4)	P_6	-	P_3	-
a_{14} (2)	P_6	-	P_3	-
a_{15} (15)	P_6	-	P_3	-
a_{16} (2)	P_6	-	P_3	-
a_{17} (2)	P_6	-	P_3	-
a_{18} (91)	P_6	-	P_3	-
a_{19} (10)	P_6	-	P_3	-
a_{20} (62)	P_6	-	P_3	-
a_{21} (7)	P_6	-	P_3	-
a_{22} (1)	P_6	-	P_3	-
a_{23} (23)	P_6	-	P_3	-
a_{24} (0)	P_6	-	P_7	-
a_{25} (3)	P_6	-	P_7	-
a_{26} (5)	P_6	-	P_3	-
a_{27} (1)	P_6	-	P_7	-
a_{28} (5)	P_6	-	P_3	-
a_{29} (7)	P_6	-	P_3	-
a_{30} (19)	P_6	-	P_3	-
a_{31} (17)	P_6	-	P_3	-
a_{32} (25)	P_6	-	$2P_3$	-
a_{33} (80)	P_6	-	P_7	-
a_{34} (4)	P_6	-	P_3	0
a_{35} (19)	P_6	-	P_7	-
a_{36} (5)	P_6	-	P_7	0
a_{37} (15)	P_6	-	P_7	0

TABLE 4-5. RUN 2 OBJECTIVE FUNCTION VALUES P_k* (cont'd)

a_j	Run 1		Run 2	
	d^-	d^+	d^-	d^+
F. Distribution by Organizational Goals and User Needs				
F.1.1 Managers vs. Scientists and Engineers				
a_{38} (1:7)	P_3	P_3	P_5	P_5
F.1.2 Libraries (workload)				
a_{39} (355,020)	P_3	-	P_5	-
a_{40} (365,671)	P_3	-	P_5	-
a_{41} (390,000)	P_3	0		0
F.2 Functional Goals				
a_{42} (18%)	P_3	P_3	P_5	P_5
a_{43} (25%)	P_3	P_3	P_5	P_5
a_{44} (52%)	P_3	P_3	P_5	P_5
a_{45} (25%)	P_3	P_3	P_5	P_5
a_{46} (10%)	P_3	P_3	P_5	P_5
a_{47} (15%)	P_3	P_3	P_5	P_5
a_{48} (5%)	P_3	P_3	P_5	P_5
F.3 Responsiveness to Users				
a_{49} (20%)	P_3	P_3	P_4	P_4
a_{50} (20%)	P_3	P_3	P_4	P_4

*P_k is the priority order assigned to indicate the importance of minimizing the respective deviations from the goal criteria. a_j. P_1 is the highest priority.

0 indicates an impractical solution not to be considered in the model whereas a blank indicates the deviational variable is in the model, but not in the objective function.

**The numerial values for a_j are explained in Section III with the description of the basic model.

The constraint on the total staff has been modified to allow more flexibility in the solution. Priority one (P_1) sets a goal of at least 454 man-years in the solution. Priority two (P_2) sets the limit at 491. The goal not to exceed 454 (d_2^+) has been deleted. Priority three (P_3) now states that the projects deemed essential to DDC's operation should be allocated resources as indicated. Among the essential projects the administrator indicated that project Y_{45} (the DDC System Redesign and Implementation Effort) is twice as important as the others. Thus, the weighted priority ($2\ P_3$) is indicated in the table. Priority four (P_4) specifies a basic services goal of 85% of the total program, and attainment of goal criteria F.3, Responsiveness to Users (a_{49} and a_{50}). Priority five (P_5) specifies the goal to have 15% of total program devoted to investment projects and to meet the other organizational goals (a_{38} through a_{48}). The sixth priority (P_6) is to apportion the resources among the projects according to their relative effectiveness. Priority seven (P_7) sets target levels for the non-essential projcets. Priority eight (P_8) is the cost minimization goal which is again left at the lowest priority and set to zero in order to calculate the cost of the optimal solution.

4.4.3 Solution (Run 2)

The solution calculated for the second run is illustrated in Tables 4-6, 4-7 and 4-8. The format is the same as Run 1.

4.4.4 Analysis of the Solution (Run 2)

The output now indicates that 27 of the 30 projects are represented in the solution (Table 4-7). Only projects Y_{32} (Integrated R&D Information System), Y_{34} (General Systems) and Z_{52} (Technical Terminology) are without sufficient justification in the model to receive resources.

The degree of goal attainment is much improved over the first run. Table 4-8 indicates that the four top priorities are

TABLE 4-6. SLACK ANALYSIS (RUN 2)

Project Codes	ROW (aj.)	AVAILABLE	POS-SLK	NEG-SLK
	1	491	0	0
	2	454	37	0
	3	0	9369	0
	4	0	0	0
	5	363	0	220
	6	0	2	0
	7	68	0	55
11	8	13	0	0
12	9	13	0	0
13	10	1	0	0
15	11	2	0	0
16	12	1	0	0
17	13	4	0	0
18	14	2	0	0
19	15	15	44	0
191	16	2	0	0
192	17	2	0	0
21	18	91	0	0
22	19	10	0	0
23	20	62	5	0
24	21	7	0	0
25	22	1	0	0
26	23	23	58	0
31	24	0	12	0
32	25	3	0	3
33	26	5	0	0
34	27	1	0	1
41	28	5	0	0
42	29	7	0	0
43	30	19	0	0
44	31	17	11	0
45	32	25	0	0
51	33	80	0	68
511	34	4	0	0
52	35	19	0	19
53	36	5	0	0
60	37	15	0	0
	38	0	0	0
	39	355020	35502	0
	40	365671	24851	0
	41	390522	0	0
	42	0	43	0
	43	0	0	46
	44	0	102	0
	45	0	0	62
	46	0	0	28
	47	0	0	69
	48	0	0	19
	49	0	0	0
	50	0	0	0

TABLE 4-7. VARIABLE ANALYSIS (RUN 2)

Symbol	Name	Variable No.	Amount
Z_{51}	Management and Administration	26	12.00052
Y_{45}	DDC Sys Redesign and Imple	25	24.99998
X_{11}	R&T WUDB Input	1	13.00000
X_{12}	R&T WUDB Output	2	13.00000
X_{13}	STINFO S/R Data Bank	3	1.00000
X_{15}	R&D Prog Plang DB Input	4	2.00000
X_{16}	R&D Prog Plang DB Output	5	1.00000
X_{17}	Indep R&D Data Bank Input	6	4.00000
X_{18}	Indep R&D Data Bank Output	7	2.00000
X_{19}	RDT&E On-Line Terminal	8	59.00037
X_{191}	RDT&E On-Line Terminal at Boston	9	2.00000
X_{192}	RDT&S On-Line Terminal at L.A.	10	2.00000
X_{22}	Tech Report Announcement	12	10.00000
X_{24}	Tech Rpt Automatic Distr	14	7.00000
X_{25}	Tech Rpt Primary Distr	15	1.00000
X_{26}	Tech Rpt Bibliographies	16	80.09311
X_{31}	Advanced Distr Systems	17	11.74989
X_{33}	Natural Language Systems	19	5.00000
X_{41}	RDT&E Information Services	21	5.00000
Y_{42}	Technical Report Systems	22	7.00000
Y_{43}	Integrated Systems	23	19.00000
Y_{44}	RDT&E On-Line System	24	27.99962
$Z_{5.1.1}$	4 People for Promotion & Markg	27	4.00000
$Z_{5.3}$	STINFO Central Registry	29	5.00000
$Z_{6.0}$	Support of Non-DDC Act	30	15.00000
$X_{2.3}$	Tech Report Request Distr	13	66.15651
$X_{2.1}$	Tech Report Input	11	91.00000

TABLE 4-8. ANALYSIS OF THE OBJECTIVE (RUN 2)

PRIORITY	UNDER-ACHIEVEMENT
8	9369
7	90
6	275
5	367
4	0
3	0
2	0
1	0
ARTIFICIAL	0

fully achieved (P_1 to P_4).[4] The solution calls for 491 man-years of effort and the staff goal permitted a range from 454 to 491 (P_1 and P_2). Priority three (P_3) specified that the essential projects should receive at least the man power provided in the Program/Budget, which was achieved. Priority four (P_4) designated that 85% of the program should be "basic" services, and also that the user need goals be met. The solution meets these criteria.

A key feature governing the solution appears to be the goal criteria that 85% of the program be devoted to basic services. This is indicated by the underachievement of priority five (P_5). According to the model, any solution which would improve P_5 (the organizational goals) would adversely affect P_4. The same condition is true of priorities six and seven.

Priority eight is the cost minimization goal which indicates a labor cost of approximately $9,369.000. This represents a slight deterioration from the first solution as it is 6.73% over the 1978 Program/Budget (i.e. $8,778,000) compared to a 5.58% increase in the first run.

With respect to the 50 goal criteria, Table 4-6 provides more detailed information of value to the decision-maker.

The fact that the model calls for 491 man-years of effort suggests that additional staff (from contract services, if necessary) ought to be considered for the 1978 Program/Budget in order to maximize the overall degree of goal attainment. It appears that so long as there are technical deficiencies in the proposed program, the model will utilize all available resources in an attempt to minimize them.

The Slack Analysis (Table 4-6) identifies the investment aspect of the program as the most deficient area in this solution and the area likely to benefit if additional staff were available. Specifically, for goal criteria a_{42} through a_{47} where the even numbers indicate goals related to the basic program and the odd numbers

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[4] As noted previously, the artificial priority does not change the net outcome of the model.

indicate goals related to the investment program, the solution demonstrates a severe imbalance with respect to the investment goals. This is shown by the negative slack values for all the odd numbered investment goals.

Similarly, the model's resource allocation to projects Y_{31} through Y_{34} (a_{24} - a_{27}) indicate a poor relationship between the proposed development projects in the 1978 Program/Budget and the stated organizational goals. Of the projects set at priority seven (P_7), Y_{32} (Integrated R&D Information System) and Y_{34} (General Systems) were completely unachieved. Project Y_{31} (Advanced Distribution Systems) was allocated 11 man-years even though the target level for 1978 is zero. This indicates that purposes served by X_{31} are more closely related to the organizational goals than the other development projects planned for 1978.

The solution values for the RDT&E on-line project (X_{19}, X_{191} and X_{192}) which includes the remote access terminals at Boston and Los Angeles provide an interesting comparison with the first run solution. With the revised priorities, the target level for the Boston and Los Angeles facilities are now supported. In addition, the solution calls for increased support of the RDT&E on-line effort by nearly 300%, whereas in Run 1 it was virtually unsupported. This result can be accounted for by the fact that in Run 2 the goal of an 85% basic program was a higher priority than the organizational goals. This indicates that the RDT&E on-line project is particularly sensitive to the desired ratio of basic services to investment services but not to the organizational goals.

A second project that appears to be sensitive to the 85% basic program criteria is X_{26}, Technical Report Bibliographies, (a_{23}). The model calls for more than doubling this project.

The slack analysis brings out additional points of interest with respect to the accuracy of the model. Project Y_{44} (a_{31}) is provided 11 additional man-years. Y_{44} is the systems support effort for the RDT&E on-line system. This response is consistent with the model's heavy support of the on-line service in project X_{19}.

In another respect the model's completeness is questionable. Projects Z_{51} and Z_{52} which represent the administrative support effort are significantly underachieved. Assuming that the administration must be proportionate to the technical staff, a constraint may be needed to specify a desired ratio of administrative staff to total staff.

4.4.5 Implications of the Results

The investment resources represent the agency's ability to remain current with the technology of information processing. Consequently, if the imbalance between basic and investment efforts seen in the 1978 Program/Budget plan were to be maintained over a period of several years, the agency is likely to fall behind in its technological capability.

4.5 RUN 3

The third run is directed toward demonstrating the use of the model to consider the effect of changing a single parameter in the decision-maker's priority structure.

4.5.1 Relationship of the Third Run to the Decision Problem

In the first two runs the estimated costs of the solutions exceeded the budget planned for the 1978 Program/Budget. Therefore, it was decided to assess the effect on the degree of goal attainment that would result from increasing the priority of the cost constraint.

4.5.2 Goal Criteria and Priorities for Run 3

Table 4-9 illustrates the goal criteria and priorities for run 3.

In this run the criterion for a_3 is changed from zero to the projected labor cost in the 1978 Program/Budget, \$8,778,000. All other criteria (a_j) remain unchanged.

The priority structure is also changed to increase the significance of the cost constraint. The goal for a staff between

TABLE 4-9. RUN 3 OBJECTIVE FUNCTION VALUES P_k^*

Goal Criteria (a_i)	Run 1		Run 2		Run 3	
	d^-	d^+	d^-	d^+	d^-	d^+
A. Total Staff						
a_1 (491)	P_2	0	-	P_2	-	P_2
a_2 (454)	P_1	P_1	P_1	-	P_1	-
B. Total Cost					a_3 = 8,778	
a_3 (0)	0	P_7	0	P_8	P_3	
C. Basic Services						
a_4 (85%)	P_4	-	P_4	P_4	P_5	P_5
a_5 (363)	P_5	0	P_6	0	P_7	0
D. Investment Services						
a_6 (15%)	P_4	-	5	5	P_6	P_6
a_7 (68)	P_5	0	P_6	0	P_7	0
E. Target Levels for Individual Programs in man-years						
a_8 (13)	P_6	-	P_3	-	P_4	-
a_9 (13)	P_6	-	P_3	-	P_4	-
a_{10} (1)	P_6	-	P_3	-	P_4	-
a_{11} (2)	P_6	-	P_3	-	P_4	-
a_{12} (1)	P_6	-	P_3	-	P_4	-
a_{13} (4)	P_6	-	P_3	-	P_4	-
a_{14} (2)	P_6	-	P_3	-	P_4	-
a_{15} (15)	P_6	-	P_3	-	P_4	-
a_{16} (2)	P_6	-	P_3	-	P_4	-
a_{17} (2)	P_6	-	P_3	-	P_4	-
a_{18} (91)	P_6	-	P_3	-	P_4	-
a_{19} (10)	P_6	-	P_3	-	P_4	-
a_{20} (62)	P_6	-	P_3	-	P_4	-
a_{21} (7)	P_6	-	P_3	-	P_4	-
a_{22} (1)	P_6	-	P_3	-	P_4	-
a_{23} (23)	P_6	-	P_3	-	P_4	-
a_{24} (0)	P_6	-	P_7	-	P_8	-
a_{25} (3)	P_6	-	P_7	-	P_8	-
a_{26} (5)	P_6	-	P_3	-	P_4	-
a_{27} (1)	P_6	-	P_7	-	P_8	-
a_{28} (5)	P_6	-	P_3	-	P_4	-
a_{29} (7)	P_6	-	P_3	-	P_4	-
a_{30} (19)	P_6	-	P_3	-	P_4	-
a_{31} (17)	P_6	-	P_3	-	P_4	-
a_{32} (25)	P_6	-	$2P_3$	-	$2P_4$	-
a_{33} (80)	P_6	-	P_7	-	P_8	-
a_{34} (4)	P_6	-	P_3	0	P_4	0
a_{35} (19)	P_6	-	P_7	-	P_8	-
a_{36} (5)	P_6	-	P_7	0	P_8	0
a_{37} (15)	P_6	-	P_7	0	P_8	0

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TABLE 4-9. RUN 3 OBJECTIVE FUNCTION VALUES P_k*

Goal criteria a_j**	Run 1		Run 2		Run 3	
	d^-	d^+	d^-	d^+	d^-	d^+
F. Distribution by Organizational Goals and User Needs						
F.1.1 Managers vs. Scientists and Engineers						
a_{38} (1:7)	P_3	P_3	P_5	P_5	P_6	P_6
F.1.2 Libraries (workload)						
a_{39} (355,020)	P_3	-	P_5	-	P_6	—
a_{40} (365,671)	P_3	-	P_5	-	P_6	—
a_{41} (390,000)	P_3	0	P_5	0	P_6	
F.2 Functional Goals						
a_{42} (18%)	P_3	P_3	P_5	P_5	P_6	P_6
a_{43} (25%)	P_3	P_3	P_5	P_5	P_6	P_6
a_{44} (52%)	P_3	P_3	P_5	P_5	P_6	P_6
a_{45} (25%)	P_3	P_3	P_5	P_5	P_6	P_6
a_{46} (10%)	P_3	P_3	P_5	P_5	P_6	P_6
a_{47} (15%)	P_3	P_3	P_5	P_5	P_6	P_6
a_{48} (5%)	P_3	P_3	P_5	P_5	P_6	P_6
F.3 Responsiveness to Users						
a_{49} (20%)	P_3	P_3	P_4	P_4	P_5	P_5
a_{50} (20%)	P_3	P_3	P_4	P_4	P_5	P_5

*P_k is the priority order assigned to indicate the importance of minimizing the respective deviations from the goal criteria, a_j. 0 indicates an impractical solution not to be considered in the model whereas a blank indicates the deviational variable is in the model, but not in the objective function.

**The numerical values for a_j are explained in Section III with the description of the basic model.

454 and 491 man-years remains at the first and second priority levels (P_1 and P_2). However, the cost constraint is introduced as priority three (P_3). All the remaining priorities are down-graded by one priority level from run 2.

In effect, the problem is essentially the same as run 2, except than the solution must also contend with the specific cost target.

The structure of run 3 is as follows:

- Total staff from 454 to 491 man-years
- Avoid budget deficit
- Sufficient staff for essential projects
- 85% basic services, responsiveness to user needs
- Meet investment service goal and organizational goal criteria
- Distribution of resources according to effectiveness
- Provide staff for the remainder of the 1978 Program/Budget

4.5.3 Solution (Run 3)

The solution calculated for the third run is illustrated in Tables 4-10, 4-11, and 4-12.

4.5.4 Analysis of the Solution (Run 3)

With the cost constraint introduced as a high priority decision factor, the model was forced to evaluate the cost/benefit ratio existing between the projects and the organizational goals.

In this solution, the degree of goal achievement, as indicated by Table 4-12 is improved to five goals achieved because the cost goal is now met. Whereas, four goals were achieved in the previous run. The improved degree of goal attainment has been achieved at the expense of certain projects which appear to be sensitive to cost.

The variable analysis, Table 4-11, shows that six projects are not represented in the solution compared to only three in run 2. In addition to the Integrated R&D Information System (Y_{32}), General

TABLE 4-10. SLACK ANALYSIS (Run 3)

Project Codes	ROW (aj.)	AVAILABLE	POS-SLK	NEG-SLK
	1	491	0	32
	2	454	5	0
	3	8778	0	0
	4	0	0	0
	5	363	0	246
	6	0	1	0
	7	68	0	54
11	8	13	0	0
12	9	13	0	0
13	10	1	61	0
15	11	2	0	0
16	12	1	0	0
17	13	4	0	0
18	14	2	0	0
19	15	15	36	0
191	16	2	0	0
192	17	2	0	0
21	18	91	0	0
22	19	10	0	0
23	20	62	4	0
24	21	7	0	0
25	22	1	0	0
26	23	23	0	0
31	24	0	8	0
32	25	3	0	3
33	26	5	0	0
34	27	1	0	1
41	28	5	0	0
42	29	7	0	0
43	30	19	0	0
44	31	17	19	0
45	32	25	0	0
51	33	80	0	80
511	34	4	0	0
52	35	19	0	19
53	36	5	0	5
60	37	15	0	15
	38	0	8	0
	39	355020	35503	0
	40	365671	24851	0
	41	390522	0	0
	42	0	100	0
	43	0	0	46
	44	0	40	0
	45	0	0	52
	46	0	0	24
	47	0	0	68
	48	0	0	19
	49	0	0	0
	50	0	0	0

TABLE 4-11. VARIABLE ANALYSIS (RUN 3)

Symbol	Name	Variable No.	Amount
X_{15}	R&D Prog Plang DB Input	4	2
X_{18}	Indep R&D Data Bank Output	7	2
X_{23}	Tech Report Request Distr	13	66
X_{17}	Indep R&D Data Bank Input	6	4
X_{19}	RDT&E On-Line Terminal	8	51
X_{191}	RDT&E On-Line Term at Boston	9	2
X_{192}	RDT&E On-Line Term at L.A.	10	2
X_{22}	Tech Report Announcement	12	10
X_{24}	Tech Report Automatic Distr	14	7
X_{25}	Tech Report Primary Distr	15	1
X_{26}	Tech Report Bibliographies	16	23
X_{31}	Advanced Distr Systems	17	8
Y_{33}	Natural Language Systems	19	5
Y_{41}	RDT&E Information Services	21	5
Y_{42}	Technical Report Systems	22	7
Y_{43}	Integrated Systems	23	19
Y_{44}	RDT&E On-Line System	24	36
Y_{45}	DDC Sys Redesign and Imple	25	25
Y_{511}	4 People for Promotion & Markg	27	4
X_{11}	R&T WUDB Input	1	13
X_{12}	R&T WUDB Output	2	13
X_{13}	STINFO S/R Data Bank	3	62
X_{16}	R&D Prog Plang DB Output	5	1
X_{21}	Technical Report Input	11	91

TABLE 4-12. ANALYSIS OF THE OBJECTIVE (RUN 3)

PRIORITY	UNDER-ACHIEVEMENT
8	123
7	300
6	367
5	0
4	0
3	0
2	0
1	0

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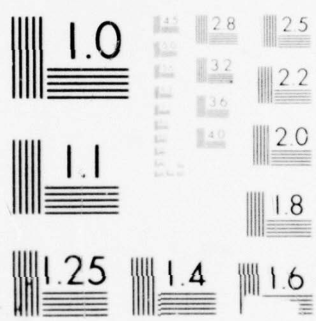

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Systems development (Y_{34}) and Technical Terminology (Z_{52}), the third run solution does not represent any management and administrative staff (Z_{51}), the STINFO Central Registry (Z_{53}) or Support of non-DDC Activities (Z_{60}).

While the solution indicates that the latter three projects are the most sensitive to a cost/benefit analysis, zero support is unfeasible. Therefore, an appropriate constraint must be defined and added to the basic model to represent administrative staff requirements.

The Slack Analysis, Table 4-10, offers somewhat less obvious insight to the cost/benefit sensitive projects. The following conclusions are based on a comparison of the slack analysis from run 3 with that of run 2.

Project X_{13}, STINFO Data Bank (a_{10}) appears to have a very favorable cost/benefit evaluation as indicated by the excessive positive slack assigned to it by the model in this run. The services designed to serve RDT&E managers also appear to have a slight cost/benefit edge over services to RDT&E scientists and engineers. This is indicated by the positive slack in row a_{38}.[5] Furthermore, the systems support for the RDT&E on-line service, Y_{44} (a_{31}) is evaluated favorably for cost/benefit.

On the negative side, of course the overall staff constraint was highly sensitive to cost. The third solution calls for only a slight increase in staff (a_1 and a_2) to 459. The decrease principally affected the three project elements noted previously, the administrative staff (Z_{51}), STINFO Central Resistry (Z_{52}) and Support for Non-DDC activities (Z_{60}).

Finally, an interesting reversal of program emphasis resulted from the addition of the cost constraint. For the goal criteria to provide basic services devoted to access to information (a_{42}) and

[5] This conclusion can be confirmed by reviewing the formulation of the manager to scientist ratio constraint in the previous section.

to provide basic services devoted to access to DDC held documents (a_{44}), the cost constrained solution emphasized (a_{44}) while the non-cost constrained solution favored a_{42}.

4.5.5 IMPLICATIONS OF THE RESULT

The results of the third run are particularly interesting because of their cost/benefit implications.

Clearly, constraints must be added to the model to provide an adequate support staff. However, the other results such as the reversal of the program emphasis from information services to document access services on the basis of cost indicate that the purpose of each goal setting action must be carefully considered prior to its inclusion in the model. As seen by this third run, the results of apparently reasonable modifications to the administrative priorities are not readily predicable.

4.6 CONCLUSIONS REGARDING THE MODEL TESTING

The study set out to answer the question, whether the goal programming technique can be applied on a practical level in DDC's complex information service environment. In that respect, it appears certain that goal programming can provide substantial assistance to the agency's decision-makers, particularly in helping to identify and resolve apparent goal conflicts among various levels of management. In addition, the technique will help DDC's decision-makers establish precise goal criteria and operating priorities.

However, the model's numerical values and constraints should be reviewed by the operating managers prior to integrating goal programming into DDC's routine management practice.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. AAI (AUERBACH Associates, Inc.) DDC 10 Year Requirements and Planning Study. Final Report. Volumes 1 and II. Prepared by Jerome T. Maddock, Thomas J. McGeehan and Martha Cornog. AAI (AUERBACH Associates, Inc.) Philadelphia, Pennsylvania, June 13, 1976 (AD-A024 700 and AD-A024 701).

2. AAI (AUERBACH Associates, Inc.) Decision Analysis Technique for Program Evaluation (Goal Programming). Statement of Goals. Prepared by Thomas J. McGeehan. AAI (AUERBACH Associates, Inc.) Philadelphia, Pennsylvania, October 23, 1976 (AUER 2325/2326-TR-6).

3. Ackoff, Russell and James Emery. Third Version of an Idealized Design of a Scientific Communication and Technilogy Transfer System. Pittsburgh, Pennsylvania. Busch Center, 1974 Wharton School, University of Pennsylvania, 1974.

4. Aines, Andrew A. and Melvin Day. National Planning of Information Services. In: Annual Review of Information Science Technology, Volume 10, Carlos A. Cuadra and Ann W. Luke, eds. Washington, D.C. American Society for Information Science, 1975, pp. 3-42.

5. Bookstein, Abraham. Allocation of Resources in an Information System. Journal of the American Society for Information Science, 25(1):52-28, January-February, 1974.

6. Bommer, Michael. The Development of a Management System for Effective Decision Making and Planning in a University Library. (Ph.D. Dissertation). University of Pennsylvania, 1971. 340 p. (University Microfilms, no. 72-17, 328).

7. Bommer, Michael. Operations Research in Libraries: A Critical Assessment. Journal of the American Society for Information Science, 26(3):137-139, May-June, 1975.

8. Buckland, Michael K. et.al. Systems Analysis of a University Library. Bailrigg, England: University of Lancaster Library. 1970. 30 p. (University of Lancaster Library Occasional Papers, No. 4).

9. Buckland, Michael K. Book Availability and the Library User. Pergamon Press, New York, 1975, 196 p.

10. Buckland, Michael K. The Management of Libraries and Information Centers. In: Annual Review of Information Science and Technology, Volume 9, Carlos A. Cuadra and Ann W. Luke, eds. Washington, D.C., American Society for Information Science, 1975, pp. 335-379.

11. Burns, Robert W. Jr. An Empirical Rationale for the Accumulation of Statistical Information. Library Resources and Technical Services, 18(3):253-258, Summer 1974.

12. Burr, Robert L. Library Goals and Library Behavior. College and Research Libraries, 36(1):27-32, 1975.

13. Charnes, A., W.W. Cooper, and Y. Ijiri. Breakeven Budgeting and Programming to Goals. Journal of Accounting Research, (1):16-43, 1963.

14. Charnes A., and W.W. Cooper. Management Models and Industrial Applications of Linear Programming, Col. I-II, John Wiley and Sons, New York, 1961.

15. Churchman, C. West, Russell L. Ackoff, and E. Leonard Arnoff. Introduction to Operations Research. John Wiley and Sons, New York, 1957, 645 p.

16. Cleverdon, Cyril W. User Evaluation of Information Retrieval Systems. Journal of Documentation, 30(2):170-180, June 1974.

17. Committee on Federal Laboratories, Federal Council for Science and Technology. Special Studies of Measurement Problems, Vol. 1. Measuring Research and Development and Grant Administration Programs. Civil Service Commission, General Accounting Office, Office of Management and Budget. October 1973. 254 pp.

18. Contini, Bruno. A Stochastic Approach to Goal Programming. Operations Research, 16(3):576-586, May-June, 1968.

19. Cooper, Michael D. The Economics of Information. In: Annual Review of Information Science and Technology, Vol. 8. Carlos A. Cuadra and Ann W. Luke, eds. Washington, D.C. American Society for Information Science, 1973 pp. 5-40.

20. Crecine, John P. A Computer Simulation Model of Municipal Budgeting. Management Science, 13(11):786-815, July 1967.

21. Dammers, H.F. Progress in Documentation: The Economics of Computer-based Information Systems - a Review. Journal of Documentation, 31(1):38-45, March, 1975.

22. Dantzig, George B. The Programming of Interdependent Activities: Mathematical Model. In: T.C. Coopmans, Activity Analysis of Production and Allocation. John Wiley and Sons, New York, 1951.

23. Debons, Anthony and R. L. Montgomery. Design and Evaluation of Information Systems. In: Annual Review of Information Science and Technology, Vol. 9, Carlos A. Cuadra, Ann W. Luke, and J. L. Harris, eds. American Society for Information Science, Washington, D.C. 1974, pp. 25-55.

24. De Prospo, Ernest R. et.al. Performance Measures for Public Libraries. Public Library Association, American Library Association, Chicago, 1973. 71 pp.

25. Evans, Edward et.al. Review of Criteria Used to Measure Library Effectiveness. Bulletin of the Medical Library Association, 60(1):102-110, January, 1972.

26. Farradane, J. The Evaluation of Information Retrieval Systems. Journal of Documentation, 30(2):195-209, June 1974.

27. Flowerdew, A.D.J. and C.M.E. Whitehead. Cost-Effectiveness and Cost Benefit Analysis in Information Science, London, England. London School of Economics and Political Science, 1974, 71 p. (OSTI Report 5206).

28. Ford, Geoffrey. Research in User Behavior. Journal of Documentation, 29(1):85-106, March 1973.

29. Fry, Bernard M. Evaluation Study of ERIC Products and Services. Summary Volume. Final Report. Indiana University, Graduate Library School, Bloomington, Indiana, March 1972. 51 pp. (ED 060 922).

30. Gibbs, Thomas E. Goal Programming. Journal of Systems Management, 24(5):38-41, May 1973.

31. Hamburg, Morris, R.C. Clelland, M. Bommer, L. Ramist, R. Whitefield. Library Planning and Decision Making Systems. MIT Press, Cambridge, Mass. 1974. 274 pp.

32. Hamburg, Morris, et.al. A Systems Approach to Library Management. Journal of Systems Engineering, 4(2):117-130, January, 1976.

33. Hindle, Anthony and Diane Raper. The Economics of Information. In: Annual Review of Information Science and Technology, Volume 11. Martha Williams, ed. Washington, D.C. American Society for Information Science, 1975, pp. 27-54.

34. Huber, George P. Methods for Quantifying Subjective Probabilities and Multi-Attribute Utilities. Decision Sciences, 5(3):430-458, October, 1974.

35. Ijiri, Yuji. Management Goals and Accounting for Control. North-Holland Publishing Company, Amsterdam, 1965.

36. Jaaskelainen, Veikko. A Goal Programming Model of Aggregate Production Planning. Swedish Journal of Economics, 2:14-19, 1969.

37. Kantor, P.B. The Library as an Information Utility in the University Context: Evolution and measurement of service. Journal of the American Society for Information Science, 27(2):100-112, March-April, 1976.

38. Kaplan, Abraham. The Conduct of Inquiry, Methodology for Behavioral Sciences. Chandler Publishing Co. Scranton, Pa. 1964, 428, p.

39. Katter, Robert V. Design and Evaluation of Information Systems. In: Annual Review of Information Science and Technology, Vol. 4 Carlos A. Cuadra and A. W. Luke, eds. Encyclopedia Britannica, Chicago, 1969. pp. 31-70.

40. King, E.W. et.al. Statistical Indicators of Scientific and Technical Communication (1960-1980). Vol. II: A Research Report. King Research, Inc. Rockville, Md. Center for Quantitative Sciences, May 1976. 505 p. (PB-254 060/2WL)

41. Knutsen, K. and R.L. Nolan. Assessing Computer Costs and Benefits. Journal of Systems Management, 25(2):28-34, February, 1974.

42. Koba Associates, Inc. A Study to Validate and Evaluate the WIN II Information System. Koba Associates, Inc. Washington, D.C. May 1974. 49 pp.

43. Kochen, Manfred and Karl Deutsch. Toward a Rational Theory of Decentralization: Some Implications of a Mathematical Approach. American Political Science Review, 63:34-49, 1969.

44. Koopmans, Tjalling C. Activity Analysis of Production and Allocation. John Wiley and Sons, New York, 1951.

45. Kraft, Donald H. and Thomas W. Hill. A Mathematical Model of the Information Center Location Problem and its Implication for Decision Makers. University of Maryland, School of Library and Information Service, College Park, Md. 1962. 35 pp. (unpublished).

46. Krevitt, Beth I. and Belver C. Griffith. Evaluation of Information Systems: A Bibliography, 1967-1972. ERIC Clearinghouse on Library and Information Sciences, December, 1973. 35 pp. (ED 083 988).

47. Ladendorf, Janice. Information Service Evaluation. The Gap Between the Ideal and the Possible. Special Libraries, 64(7):273-279, July 1973.

48. Lancaster, F.W. The Cost-Effectiveness Analysis of Information Retrieval and Dissemination Systems. Journal of the American Society for Information Science, 22(1):12-27, January-February, 1971.

49. Lancaster, F.W. et.al. Evaluating the Effectiveness of an On-line Natural Language Retrieval System. Information Storage and Retrieval 8(5):223-245, October, 1972.

50. Lee, Sang M. Goal Programming for Decision Analysis. AUERBACH, Philadelphia, Pa. 1972.

51. Lee, Sang and E. Clayton. A Goal Programming Model for Academic Resouce Allocation. Management Science, 18(8):395-408, April 1972.

52. Leggate, P. Computer-Based Current Awareness Services. Journal of Documentation, 31(2):93-115, June, 1975.

53. Leimkuhler, Ferdinand F. and Alice Billingsley. Library and Information Center Management. In: Annual Review of Information Science and Technology, Vol. 7, Carlos A Caudra and Ann W. Luke, eds. Washington, D.C. American Society for Information Sciences, 1972. pp. 499-534.

54. Leimkuhler, Ferdinand F. Operations Research and Information Science - A Common Cause. Journal of the American Society for Information Science, 24(1):3-8, January-February, 1973.

55. Lynch, Beverly P. The Academic Library and Its Environment, College and Research Libraries, 35(2):126-132, March, 1974.

56. Marchant, Maurice P. The Effects of the Decision Making Process and Related Organizational Factors on Alternative Measures of Performances in University Libraries. (Ph.D. Dissertation) University of Michigan, Ann Arbor, 1970.

57. Martyn, John. Resources Research: Aslib R&D and the Future. Aslib Proceedings, 27(1):16-21, January, 1975.

58. Michael, Mary Ellen and Arthur P. Young. Planning and Evaluating Library System Services in Illinois. University of Illinois. Library Research Center, Urbana, Ill. August 1974. 78 pp.

59. Millham, Charles B. A Simulation Model and Data for Library Planning. Washington State Library, Library Development Division, Olympia, Wash. June 1975. 91 p. (ED 112 857)

60. Mintzberg, H. et.al. The Structure of Strategic Decision Processes. Aix-en-Provence, France: Universite de Droit, d'Economic et des Sciences d'Aix-Marsecille, Instite d'Administration des Exterprises, April 1975.

61. Monroe, Margaret E. Evaluation of Public Services for Adults. Library Trends, 22(3):337-359, January 1974.

62. Morse, Philip M. Library Effectiveness: A Systems Approach. MIT Press Cambridge, Mass, 1968. 207 pp.

63. Murdock, John and John Sherrod. Library and Information Center Management. In: Annual Review of Information Science and Technology, Vol. II. Martha Williams ed. Washington, D.C. American Society for Information Science, 1975, pp. 381-402.

64. New England Board of Higher Education. A Technical and User Audit of the Shared Cataloging Support Sub-system of the New England Board of Higher Education, Wellesley, Mass. June 1973, 253 pp. (ED 081 439)

65. Orr, R.H. et.al. Development of Methodologic Tools for Planning and Managing Library Services (Three Part Series). Bulletin of the Medical Library Association. 56:235-240, 241-267 and 380-403, 1968.

66. Orr, Richard H. Measuring the Goodness of Library Services: A General Framework for considering Quantitative Measures. Journal of Documentation, 29(1):315-332. September, 1973.

67. Pitkanen, Eero. Goal Programming and Operational Objectives in Public *Administration. Swedish Journal of Economics*, 72(3):207-214, 1970.

68. Presanis, A. and B.C. Brookes. Compendex Evaluation Project. University College, School of Library, Archieve and Information Studies, London, England, July 1973. 81 pp. (OSTI report 5182).

69. Price, Douglas S. Collecting and Reporting Real Costs of Information Systems. American Society for Information Science, Washington, D.C. November 1971. 160 pp. (ED 055 593).

70. Pritchard, Alan. The Library as an Industrial Firm, An Approach to Library Management. City of London Polytechnic Library and Learning Resources Service, London, England, December 1973, pp. 17.

71. Purdue University. School of Industrial Engineering. A Progress Report of Eight-Months Effort on Grant No. SIS 75-14772. The Economic Characteristics of Information Analysis Centers. Submitted to the National Science Foundation, August 1976.

72. Raffel, Jeffrey A. From Economic to Political Analysis of Library Decision Making. College and Research Libraries, 35(6)L412-423, November, 1974.

73. Rawles, Beverly A. Planning the Expansion of Library Services to Disadvantaged Adults. Morehead State University, Appalachian Adult Education Center, Morehead, Ky. May, 1974. 16 pp.

74. Rees, Alan. Contemporary Problems in Technical Library and Information Center Management: A State-of-the Art. American Society for Information Science, Washington, D.C. 1974. 230 p.

75. Rouse, William B. Optimal Resource Allocation in Library Systems. Journal of the American Society for Information Science, 26(3):157-164, May-June, 1975.

76. Rouse, William B. A Library Network Model. Journal of the American Society for Information Science, 27(2):88-99, March-April, 1976.

77. Ruefli, Timothy W. PPBS - An Analytical Approach. In: R. Byrne, A. Charnes, W. Cooper, O. Davis and D. Gilford, Studies in Budgeting, Volume II of Studies in Mathematical and Managerial Economics, Henri Theil, ed. American Elsevier, New York, 1971.

78. Saracevic, Tefko. Relevances: A Review of and a Framework for the Thinking on the Notion of Information Science. Journal of the American Society for Information Science, 26(6):321-343, November-December, 1975.

79. Scheffler, Frederic L. Optimization of Retrieval Techniques and File Structures for the CIRCOL System. University of Dayton, Research Institute, Dayton, Ohio, February, 1974. 148 pp. (RADC-TR-73-420).

80. Scholz, William H. A Mathematical Model for Comparison of Bibliographic Data Bases. Journal of the American Society for Information Science, 27(3):183-184, May-June, 1976.

81 Smith, William A. and Ben L. Wechsler. Planning Guide for Information System Evaluation Studies. American Institute of Industrial Engineers, Inc. Computer and Information Systems Division, Norcross, Ga. August, 1973, 98 pp. (AIIE-C&TS-73-4).

82. Stanton, Robert O. Applying the Management-by-Objectives Technique in an Industrial Library. Journal of the American Society for Information Science, 26(6):313-317, December 1975.

83. Suchman, Edward A. Evaluative Research, Principles and Practice in Public Service and Social Action Programs. Russell Sage Foundation, New York, 1967.

84. Summers, F. William. The Use of Formulae in Resource Allocation. Library Trends, 23(4):631-642, April, 1975.

85. Swanson, Rowena, W. Design and Evaluation of Information Systems. In: Annual Review of Information Science and Technology, Volume 10, Carlos A. Cuadra and Ann W. Luke, eds. Washington, D.C. American Society for Information Science, 1975, pp. 43-101.

86. Swanson, Rowena W. Performing Evaluation Studies in Information Science. Journal of the American Society for Information Science, 26(3):140-156, May-June, 1975.

87. Trinkl, Frank L. Allocations Among Programs Having Counter-active Outcomes. Policy Sciences, 3(2):163-172, 1972.

88. U.S. National Commission on Libraries and Information Science. Toward a National Program for Library and Information Services: Goals for Action. Washington, D.C.: Government Princing Office, June 1975. 106 p.

89. University of Durham. Project for Evaluating the Benefits from University Libraries (PEBUL). Final Report - October 1969, Durham, England.

90. Urquhart, Donald J. The National Role in Resource Allocation. Library Trends, 23(4):595-601, April, 1975.

91. Vickers, Geoffrey. The Art of Judgement: A Study of Policy Making. London, England. Chapman and Hall, 1969.

92. Wanger, J. and M.A. Henderson. Evaluation Study of NCEC Information Analysis Products: Final Report, in two Volumes. Systems Development Corp. Falls Church, Va. June 1972 (Report Nos. TM-WD-5506 and TM-WD-5507).

93. Webster, Duane E. The Management Review and Analysis Program: An Assested Self Study to Secure Constructive Change in the Management of Research Libraries. College and Research Libraries, 35(2):114-125, March 1974.

94. Weinberg, Charles B. The University Library: Analysis and Proposals. Management Science, 21(2):130-140, 1974.

95. Wills, Gordon, and Christine Oldman. A Longitudinal Study of the Costs and Benefits of Selected Library Services: Initial Exploration and Framework. Cranfield, England. Cranfield School of Management, 1974. 28 p.

96. Wilson, John H. Jr. Costs, Budgeting and Economics of Information Processing. In: Annual Review of Information Science and Technology, Volume 7. Carlos A. Cuadra and Ann W. Luke, eds. Washington, D.C. American Society for Information Science, 1972, pp. 39-67.

97. Wolfe, J.N. et.al. The Economics of Technical Information Systems. Praeger, New York, 1974. 169 pp.

APPENDIX A.

Administrators' Interview Summary

TABLE A-1. LIST OF PARTICIPANTS

Dr. John Allen
Deputy Director (Research and Advanced Technology)
Office of the Director, Defense Research and Engineering

Dr. Walter Beam
Deputy for Advanced Technology
Office of the Secretary, Air Force (R&D)

Richard G. Bruner
Executive Director, Executive Directorate,
Technical and Logistics Services

William J. Cassell
Comptroller, Defense Supply Agency

Col. Patrick Caulfield
Director of Laboratory Plans and Programs
AFSC
Andrews AFB

Richard D. Douglas
Direcotor, Directorate of Technical Services,
Defense Documentation Center

Dr. K.C. Emerson
Deputy for Science and Technology
Office of the Assistant Secretary of the Army (R&D)

Col. Richard E. Kahler
USAD STINFO
AFSC DLX B
Andrews AFB

Edward J. Kolb
DARCOM (STINFO)
Army Material Command

Dr. Sam Koslov
Special Assistant (Science)
Office of the Assistant Secretary of the Navy (R&D)

Dr. William L. Lehmann, Director
USAF Office of Scientific Research

Herman W. Miles
Deputy Administrator, Defense Documentation Center

P.B. Newton
Technical Information Office
DCNM Development
Office of the Chief of Navel Development

Paul A. Robey, Jr.
Director, Directorate of Technical Services,
Defense Documentation Center

Hubert E. Sauter
Administrator, Defense Documentation Center

James H. Terrell
Special Assistant (Technical Information)
Office of the Deputy Director, Defense Research and Engineering

TABLE A-2. GOAL ORIENTED PROGRAM STRUCTURE DERIVED FROM ADMINISTRATIVE INTERVIEWS

Goal 1: Conduct Projects to Aid in Identifying and Locating Information as Opposed to Documents

1.1 To Provide a Basic Level of Products and Services

1.1.1 To RDT&E Managers

- provide service hours (by class of activity, e.g., input vs. output)
- provide computer systems support
- provide purchased services and material

1.1.2 To Scientists and Engineers

- provide service hours (by class)
- provide computer systems support
- provide purchased services and material

1.2 To Provide an Improved Level of Products and Services

1.2.1 To RDT&E Managers

- provide service hours (by class of activity, e.g., input vs. output)
- provide computer systems support
- provide purchased services and material

1.2.2 To Scientists and Engineers

- provide service hours (by class)
- provide computer systems support
- provide purchased services and material

1.3 To Provide an Advanced Level of Products and Services

1.3.1 Investigate

- service hours
- purchased services and material

1.3.2 Develop

- service hours
- purchased services and material

1.3.3 Implement

- service hours
- purchased service and material

Goal 2: Conduct Projects to Provide Access to DoD Documents

2.1 To Provide a Basic Level of Service and Products

2.1.1 To RDT&E Managers

- provide service hours
- provide computer systems support
- provide purchased services and material
- provide a document inventory

2.1.2 To Scientists and Engineers

- provide service hours
- provide computer systems support
- provide purchased services and material
- provide a document inventory

2.1.3 To Non-DoD Users

2.2 To Provide an Improved Level of Products and Services

2.2.1 To RDT&E Managers

- provide service hours
- provide computer systems support
- provide purchased services and material
- provide a document inventory

2.2.2 To Scientists and Engineers

- provide service hours
- provide computer systems support
- provide purchased services and material
- provide a document inventory

2.2.3 To Non-DoD Users

2.3 To Provide an Advanced Level of Products and Services

2.3.1 Investigate

- service hours
- purchased services and material

2.3.2 Develop

- service hours
- purchased service and material

2.3.3 Implement

- service hours
- purchased service and material

Goal 3: Conduct Projects to Provide Access to Documents in Remote Locations

(not a current service)

3.1 To Provide an Improved Level of Products and Services

3.1.1 To Coordinate and Administer Interagency Access Agreements

3.1.2 To Provide an Interagency Network Capability

- informed personnel for retrieval and consultative service
- intersystem computer interchange

3.2 To Provide an Advanced Level of Products and Services

3.2.1 Investigate

- service hours
- purchased services and material

3.2.2 Develop

- service hours
- purchased service and material

3.2.3 Implement

- service hours
- purchased services and material

Goal 4: Conduct Projects to Promote Use of Information Products and Services

4.1 To Promote Use Among RDT&E Managers

- publications, advertisements, exhibits
- seminars and education programs
- personal contact (user oriented reference personnel, promoters)
- user guides

4.2 Promote Use Among Scientists and Engineers

- publications, advertisements, exhibits
- seminars and education programs
- personal contact (user oriented reference personnel, promoters)
- user guides

4.3 To Promote Use Among Non-DoD Groups

4.3.1 DoD Contractors

- publications, advertisements, exhibits
- seminars and education programs
- personal contact (user oriented reference personnel, promoters)
- user guides

4.3.2 Technical Groups

- publications, advertisements, exhibits
- seminars and education programs
- personal contact (user oriented reference personnel, promoters)
- user guides

4.3.3 General Public

- publications, advertisements, exhibits
- seminars and education programs
- personal contact (user oriented reference Personnel, promoters)
- user guides

Goal 5: Administration

5.1 To Administer DDC Services

5.1.1 To Fund Services

- DoD R&D funds
- user charges
- interagency cooperative funding for advanced products and services

5.1.2 To Administer Personnel

- maintain full production capacity
- specify staff positions by staff skill and characteristics
- specify total number of staff
- specify the distribution of staff by project
- specify salary and grade levels

5.2 To Plan DDC Services

5.2.1 To Prepare Programs, Projects and Budgets

5.2.2 To Set Target Levels for the Output of Products and Services

5.2.3 To Provide Resources for DDC Development Projects

5.3 To Provide Support for Services

5.3.1 To Provide Systems Support

- Provide for systems upgrading and equipment replacement

5.3.2 To Purchase Materials

- supplies
- contract services

APPENDIX B.

Arbitrary Signs and Symbols

Arbitrary Signs and Symbols

Signs and Symbols	Meaning
$\sum$	Summation
π	Product
d^+	Positive deviation from a goal; over extension
d^-	Negative deviation from a goal; under achievement
( )	Parentheses — indicate that the quantities enclosed within are to be taken together
[ ]	Brackets — indicate that the quantities enclosed within are to be taken together
x, y, z	Decision variables: x represents a basic variable y represents an investment variable z represents miscellaneous variables

AAI

APPENDIX C.

Data Tables Used in the Construction of the DDC Model

TABLE C-1. DECISION VARIABLES*

Sequence No.	Decision Variable	Name	Basic/Investment
1	$x_{1.1}$	R&T WUDB Input	B
2	$x_{1.2}$	R&T WUDB Output	B
3	$x_{1.3}$	STINFO S/R Data Bank	B
4	$x_{1.5}$	R&D Prog Plang DB Input	B
5	$x_{1.6}$	R&D Prog Plang DB Output	B
6	$x_{1.7}$	Indep R&D Data Bank Input	B
7	$x_{1.8}$	Indep R&D Data Bank Output	B
8	$x_{1.9}$	RDT&E On-Line Terminal	B
9	$x_{1.9.1}$	RDT&E On-Line Terminal at Boston	B
10	$x_{1.9.2}$	RDT&E On-Line Terminal at Los Angeles	B
11	$x_{2.1}$	Technical Report Input	B
12	$x_{2.2}$	Tech Report Announcement	B
13	$x_{2.3}$	Tech Report Request Distr	B
14	$x_{2.4}$	Tech Report Automation Distr	B
15	$x_{2.5}$	Tech Report Primary Distr	B
16	$x_{2.6}$	Tech Report Bibliographies	B
17	$y_{3.1}$	Advanced Distr Systems	I
18	$y_{3.2}$	Integrated R&D Info Sys	I
19	$y_{3.3}$	Natural Language Systems	I
20	$y_{3.4}$	General Systems	I
21	$y_{4.1}$	RDT&E Information Services	20I : 80B
22	$y_{4.2}$	Technical Report Systems	20I : 80B
23	$y_{4.3}$	Integrated Systems	60I : 40B
24	$y_{4.4}$	RDT&E On-Line System	50I : 50B
25	$y_{4.5}$	DDC Sys Redesign and Imple	I 100%
26	$z_{5.1}$	Management and Admin	
27	$z_{5.1.1}$	4 People for Promotion & Marketing	B
28	$z_{5.2}$	Technical Terminology	B
29	$z_{5.3}$	STINFO Central Registry	Z
30	$z_{6.0}$	Support of Non-DDC Act	Z

*Decision Variables are the program elements to which labor resources must be allocated.

TABLE C-2. SOURCES OF DATA

CONSTRAINTS		SOURCE OF DATA
Symbol	Description	
x, y, z	decision variables, projects to be evaluated (Table C-1)	1978 program budget as modified by DDC management.[1]
a_1	Upper limit on the number of staff feasible (10% over previous year, i.e. 491)	Administration Interview
a_2	Total staff targeted for the 1978 Program/Budget (454)	1978 Program/Budget
a_3 c_i	Available labor budget ($8,778,000) Estimated labor cost per project man-year.	1978 Program/Budget
a_4	Desired apportionment of program labor devoted to basic services (85%)	Set by management
a_5 E_i	No. of man-years available in the budget for basic services. Estimates of probable effectiveness (See Table C-3).	1978 Program/Budget Estimated by management
a_6	Desired apportinnment of program labor devoted to investment services (15%)	Set by management
a_7	No. of man-years available in the budget for basic services. Estimates of probable effectiveness (See Table C-3).	1978 Program/Budget Estimated by management
a_8 through a_{37}	Target levels for the individual programs in the 1978 Program/Budget	1978 Program/Budget

[1]Defense Documentation Center Research, Development, Test and Evaluation (RDT&E) Program/Budget Fiscal Year's, 197T/1977/1978. 27 August 1976. Defense Supply Agency. Department of Defense, Washington, D.C.

TABLE C-2. SOURCES OF DATA (cont'd)

CONSTRAINTS		SOURCE OF DATA
Symbol	Description	
a_{38}	Desired ratio of service for RDT&E managers to service for scientists and engineers (1:7)	Ratio set by management. Principal group served per project, identified by management.
a_{39} through a_{41} P_{23}	Number of technical reports to be distributed to libraries. Productivity coefficient per man-year	Target levels for minimum, moderate and excellent service set by management. 1978 Program/Budget
a_{42} through a_{48}	Desired apportionment of manpower among functional organization goals	The goals are derived from the administrators' interviews. The criteria and goals served per project are defined by management.
a_{49} and a_{50}	Desired apportionment to services designed for specific user needs (Timeliness, comprehensiveness)	The goals are derived from the administrators' interviews. The criteria and goals served per project are defined by management.

If an equitable destribution of resources is to be made to a list of proposed projects in accordance with effectiveness attributes, it is necessary to define a matrix of effectiveness factors and score each proposed project accordingly.

The total score, represented by E_1, determines the weight of a proposed project in competing for available resources. The higher the score, the more likely it is to receive resources.

14 effectiveness factors (ef) were used to calculate scores for the study model:

ef_1	=	1 point if the program provides aid in locating information as opposed to documents.
ef_2	=	1 point for programs which provide access to documents held by DDC.
ef_3	=	1 point for programs which provide access to documents in remote locations.
ef_4	=	1 point for programs which promote the use of information products and services.
ef_5	=	2 points for programs serving primarily RDT&E managers.
ef_6	=	1 point for programs serving primarily Scientists and Engineers.
ef_7	=	1 point for service to non-DoD users.
ef_8	=	2 points for programs serving libraries or other intermediary information organizations.
ef_9	=	3 points for programs providing ADP systems support for the overall program.
ef_{10}	=	1 point for timeliness of service (24 response time)
ef_{11}	=	1 point for volume of use (5 most used products or services)
ef_{12}	=	1 point for user satisfaction (5 most well received products/ser.)
ef_{13}	=	1 point for collection comprehensiveness
ef_{14}	=	1 point for conservation of the products of DoD RDT&E Research

Project scores were provided by DDC and are shown in Table C-3a.

TABLE C-3a. EFFECTIVENESS FACTOR SCORES FOR PROPOSED PROJECTS (e_1)

Factor / Variable	ef_1	ef_2	ef_3	ef_4	ef_5	ef_6	ef_7	ef_8	ef_9	ef_{10}	ef_{11}	ef_{12}	ef_{13}	ef_{14}	$\sum = e_1$
x_{11}	1													1	2
x_{12}	1				2		1	2			1				7
x_{13}	1		1			1	1	2							6
x_{15}	1												1		2
x_{16}	1				2			2							5
x_{17}	1														1
x_{18}	1				2			2							5
x_{19}	1	1				1	1	2		1		1			8
x_{191}	1	1				1	1	2		1					7
x_{192}	1	1				1	1	2		1					7
x_{21}		1	1										1	1	4
x_{22}		1				1	1	2			1	1			7
x_{23}		1				1	1	2			1	1			7
x_{24}		1				1	1	2			1	1			7
x_{25}		1				1		2							4
x_{26}	1	1	1			1	1	2			1	1			9
y_{31}	1	1				1		2							5
y_{32}	1		1			1	1	2							6
y_{33}	1					1	1	2							5
y_{34}	1	1													2
y_{41}	1								3						4
y_{42}		1							3						4
y_{43}	1								3						4
y_{44}	1	1							3	1					6
y_{45}	1	1							3						5
z_{51}															
z_{511}				1											1
z_{52}	1														1
z_{53}															
z_{60}			1												1

The scores in Table C-3a represent a measure of the ability of each project to contribute to meeting specific organizational goals. Both new and old projects are evaluated on an equal basis in this measure. However, it is important to recognize that drastic program changes including discontinuing established projects in favor of new ones can be counter-productive. Therefore, a second aspect of probable effectiveness is considered: the willingness of management to commit resources to specific projects, e_2. This second measure will tend to favor the established projects.

The value of e_2 is implied by the proportion of resources assigned each project in the 1978 Program/Budget. Values supplied for the model are shown in Table C-3b.

TABLE C-3b. PROPORTION OF RESOURCES TARGETED FOR 1978 PROJECTS

Variable	Variable %
x_{11}	.028
x_{12}	.028
x_{13}	.002
x_{15}	.004
x_{16}	.002
x_{17}	.009
x_{18}	.004
x_{19}	.033
x_{191}	.004
x_{192}	.004
x_{21}	.199
x_{22}	.022
x_{23}	.136
x_{24}	.015
x_{25}	.002
x_{26}	.05
y_{31}	0
y_{32}	.007
y_{33}	.011
y_{34}	.002
y_{41}	.011
y_{42}	.015
y_{43}	.042
y_{44}	.037
y_{45}	.061
z_{51}	.175
z_{511}	.009
z_{52}	.042
z_{53}	.011
z_{60}	.033

APPENDIX D.

Setting up Goal Program Problems for Computer Solution

This appendix presents step-by-step procedures for setting up goal program problems for computer solution. The format is designed for the computer program listed at the end of the appendix. It discusses the data input process, the computer deck set-up, and the interpretation of the reports that are generated. The program as described by Lee, is capable of solving problems with up to 125 variables (including slack variables), 60 constraints and 10 priority levels.[1]

DATA INPUT PROCESSES

To illustrate the data input process, the problem described in Section III of this report is described. However, as the DDC model consists of 50 goal criteria (constraints) and 30 variables only a few exmaples will be used to illustrate the procedures.

A. Preparing the Data for Keypunch Card Input

The problem input deck has five parts: (1) problem card, (2) the sign card, (3) the objective function, (4) the substitution rates, and (5) the right-hand side.

1. The Problem Card

The problem card defines the problem parameters. Its format is:

Col. 1-4: punch PROB
Col. 5-7: the number of constraints and/or goals
Col. 8-10: the number decision variables (i.e. projects)
Col. 11-13: the number of priority factors

The constraints of course, refer to the number of goal criteria. The decision variables refer to the number of projects to be evaluated. The number of priority factors represents the number of actual priority levels perceived by management. Artificial priorities may be automatically created by the program in order to create the first basis.

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[1] Sang Lee, Goal Programming for Decision Analysis, AUERBACH, Philadelphia, Pa. 1972.

For the initial DDC model, there are 50 constraints, 30 projects and seven priority levels as illustraed in Figure 1.

	Card Identification	No. Constraints	No. Decision Variables	No. of Priority Levels
Col	1 2 3 4	5 6 7	8 9 10	11 12 13
	P R O B	0 5 0	0 3 0	0 0 7

Figure 1. The Problem Card

2. The Sign Card

The sign card describes the "goal" with respect to each constraint. The model is permitted to seek solutions in accordance with the following four parameters:

a. B indicates that management wants to minimize deviation in either positive or negative direction from each respective criterion. However, this also means that the model may deviate in either direction.

b. G indicates that the model may seek solutions only greater than the stated criterion. Any value less than the criterion is unfeasible and will be rejected by the model.

c. L indicates that the model may seek solutions only less than the stated criterion.

d. E indicates exactly equal. No deviation in either direction is feasible.

Example: The sign card for the initial DDC model is illustrated in Figure 2. It is derived from Table 3-8 in Section III.

Col	1	2	3	4	5	6	7	8	9	10	11	12	13	50
	L	B	G	B	L	B	L	B	B	B	B	B	B	B

Figure 2. The Sign Card

3. The Objective Function Cards

The objective function cards indicate the priority factors, the constraints they are associated with and type of deviation from the criteria (either positive or negative) that management chooses to minimize. The objective function cards are preceded by an identifier card with "OBJ" in the first three columns. The format for the objective function cards is as follows:

Col. 1-3: Key either POS (Positive) or NEG (Negative). This indicates the deviational direction that is to minimized.

Col. 8-9: The constraint with which the deviational variables are each associates.

Col. 13-14: The priority levels at which the deviational variable is to be minimized. (Both positive and negative deviation can be minimized at independent priority levels. No. 1 is the highest priority.

Col. 15-25: The weight coefficient of the priority factor. If all the variables have equal weight, 1.0 must be indicated. The decimal place must be indicated, even if the value is a zero.

Example: An example of objective function cards is provided in Figure 3 for the first 3 constraints of the initial model.

Card \ Col	1 2 3	4 5 6 7	8 9 10 11 12	13 14	15 16 17 18..25
1	O B J				
2	Neg		0 1	02	1 . 0
3	Neg		0 2	01	1 . 0
4	Pos		0 2	01	1 . 0
5	Pos		0 3	07	1 . 0

Figure 3. The Objective Function Goals

4. The Data Section Cards

The data section cards specify the coefficients of the decision variables as applied to each of the 50 constraints. There is one card for each variable in each constraint. The data section cards are identified by a preceding card with DATA punched in columns 1-4. The format for the data cards is as follows:

Col. 8-9: The constraint in which the coefficient value is located.

Col. 13-14: The number of the decision variable associated with the coefficient

Col. 15-25: The value of the coefficient

Example: For the DDC model, the data coefficients for constraints a_2 and a_3 are as illustrated in Table D-1.

TABLE D-1. DATA COEFFICIENTS FOR CONSTRAINTS a_2 and a_3

Constraint:	a_2 (Total Staff)	a_3 (Cost)
Distribution:	The sum (Σ) of all the staff assigned to each of the 30 projects	The sum (Σ) of the number of man-years times the average cost (c_i) per man-year of each of the 30 projects
Formulation:	$(1 \cdot X)+(1 \cdot Y)+(1 \cdot Z) = a_2$	$(C_i \cdot X)+C_i \cdot Y)+(C_i \cdot Z) = a_3$
Variable:	Value	Ci Value from Table 3-3
1 (X_{11})	1.0	13.92
2 (X_{12})	1.0	19.85
3 (X_{13})	1.0	20.0
4 (X_{15})	1.0	16.0
5 (X_{16})	1.0	20.0
.	.	.
.	.	.
.	.	.
30 (Z_{60})	1.0	19.07

Figure 4 illustrates the form in which the data coefficients are entered:

	Identifier							Constraint					Decision Variable		Value					
Card \ Col	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	DATA																			
2								0	2				0	1	1	.	0			
3								0	2				0	2	1	.	0			
4								0	2				0	3	1	.	0			
5								0	2				0	4	1	.	0			
6								0	2				0	5	1	.	0			
⋮									⋮					⋮		⋮				
31								0	2				3	0	1	.	0			
32								0	3				0	1	1	3	.	9	2	
33								0	3				0	2	1	9	.	8	5	
34								0	3				0	3	2	0	.	0		
35								0	3				0	4	1	6	.	0		
36								0	3				0	5	2	0	.	0		
⋮									⋮					⋮			⋮			
61								0	3				3	0	1	9	.	0	7	

Figure 4. Data Section Cards

5. The Right-Hand-Side Cards

The right-hand-side cards are preceded by a card labeled "RGHT" punched in the first four columns. The format for entering the right-hand-side values is as follows:

Col. 1-10: right-hand-side value for the first constraint (a_1)
Col. 11-20: right-hand-side value for the second constraint (a_2)
Col. 20-30: right-hand-side value for the third constraint (a_3)

. .
. .
. .

. .
. .

Col. 71-80: right-hand-side value for the eighth constraint (a_8)

When there are more than eight constraints, simply go to the next card.

Example: For the DDC example, the right-hand-side cards are (from Table 3-8):

Card \ Col	10	20	30	40 . . .	80
1	RGHT				
2	491	454	0.0	0.0	13.0
3	13.0	1.0	2.0	1.0 . . .	2.0

etc.

B. Input Card Deck Set-Up

The order of cards for the computer input deck is as follows:

1. Appropriate Systems Cards from the Computer Facility Begin Used
2. Goal Program FORTRAN Deck
3. Problem Card (PROB)
4. Sign Cards
5. Objective Function Identifier Card (OBJ)
6. Objective Function Cards
7. Data Identifier Card (DATA)
8. Data Section Cards
9. Right-Hand-Side Identifier Card (RGHT)
10. Right-Hand-Side Data Cards
11. System End Card from the Computer Facility

C. Reading of the Computer Output Reports

The computer solution provides the following output: complete printout of input data, the final simplex solution table, slack analysis report, variable analysis report, and the analysis of the objective.

As an aid to reading these reports, the following explanations are provided:

1. Input Data

The computer prints out the complete input data so that the user of the program can easily recheck the data he has fed into the computer.

For the DDC example, the computer printout is too large to present effectively as an example. Therefore, mock data are used in the following illustrations:

THE RIGHT HAND SIDE-INPUT PAGE 01

1	80.00000
2	70.00000
3	45.00000
4	90.00000

THE SUBSTITUTION RATES-INPUT PAGE 02

Row 1

1.000	0.0	0.0	0.0	-1.000	0.0	1.000	1.000

ROW 2

0.0	1.000	0.0	0.0	0.0	0.0	1.000	0.0

ROW 3

0.0	0.0	1.000	0.0	0.0	0.0	0.0	1.000

ROW 4

0.0	0.0	0.0	1.000	0.0	-1.000	1.000	1.000

THE OBJECTIVE FUNCTION-INPUT PAGE 03

PRIORITY 4

0.0	0.0	0.0	0.0	1.000	0.0	0.0	0.0

PRIORITY 3

0.0	5.000	3.000	0.0	0.0	0.0	0.0	0.0

PRIORITY 2

0.0	0.0	0.0	1.000	0.0	0.0	0.0	0.0

PRIORITY 1

1.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The Input Data Report is read as follows:

a. Right-Hand-Side Input: these are values entered for the a_j goal criteria.

b. The Substitution Rates - Input: these are coefficients entered for the data cards.

c. The Objective Function - Input: these specify the deviational variables that are to be minimized and the weights assigned to them in each priority.

These reports merely read back the data that were entered in order for the analyst to ensure that no keying errors were entered. Consequently, they should be self-explanatory. However, it should be pointed out that whenever the full model matrix is printed out, as in the substitution rates and the objective function matrices, the sequence of the data elements is as follows:

- first, all the negative deviational values are indicated (i.e. for the DDC model the first 50 data elements represent the negative deviations (d_i^-) in the complete model)
- second, the positive deviation values in the model are presented (d_i^+)
- finally, the remaining data elements represent the decision variables

For the example provided here, the first four columns represent 4 negative deviational variables, whereas the DDC model has 50. The fifth and sixth columns represent 2 positive deviational variables, whereas the DDC model has 43. The last two columns of the example are decision variables. DDC has 30 (i.e. the project list).

2. The Final Simplex Solution Table

The computer program provides the final simplex matrix. This report is primarily useful for the analyst familiar with linear programming for whom the notation is self-explanatory. As DDC personnel become skilled in the goal programming technique, it

would be advisable to consult a basic text, particularly Lee's (see Lee (50)in the bibliography) for a full explanation of the simplex solution matrix and its interpretation. However, in the introductory phase the simplex matrix is not required for the type of analysis demonstrated in Section IV.

3. The Slack Analysis Report

The Slack Analysis Report presents the input values of the right-hand-side and the final solution volues of the negative and positive variables for each equation. The slack analysis indicates the details of goal attainment; that is, the amount both under-achieved or exceeded. If both negative and positive slack values are zero, the respective has been met.

SLACK ANALYSIS PAGE 06

ROW	AVAILABLE	POS-SLK	NEG-SLK
1	80.00000	10.0000	0.0
2	70.00000	0.0	0.0
3	45.00000	0.0	25.00000
4	90.00000	0.0	0.0

The slack analysis is to be interpreted as meaning that of the four constraints (rows), numbers 2 and 4 are met. Number 1 was exceeded by 10 units (in the DDC example, that might have meant the solution called for 10 man-years more than available), and number 3 was underachieved by 25 units (for example, the number of man-year allocated to investment programs might have come up 25 positions short of what was desired).

4. Variable Analysis

The variable analysis presents the final values of the decision variables (i.e. the projects that received the resources). When the problem under consideration is a very complex one, the variable

analysis is especially helpful because it presents only the constants of the decision variables, as compared to the final simplex solution table.

The variable analysis of the mock example appears as follows:

VARIABLE ANALYSIS PAGE 07

VARIABLE	AMOUNT
1	70.00000
2	20.00000

It should be pointed out here that the variable numbers are arranged such that they refer to the list of decision variables (i.e. the projects: X, Y and Z).

5. Analysis of the Objective

An analysis of the objective presents the sum total value (Σ) for the goals in the objective. These values represent the underattained portion of goals. If the model requires assignment of artificial priority to set up the initial table, the artificial priority will also be printed out.

For the mock example, the print-out of the analysis of the objective appears as follows:

ANALYSIS OF THE OBJECTIVE PAGE 08

PRIORITY	UNDERACHIEVEMENT
4	10.00000
3	75.00000
2	0.0
1	0.0

It should be obvious that goals 1 and 2 are completely met. Goal 3 represents the value of the negative slack indicated in row 3, times a "mock" priority weight factor (in this case a weight of 3). The weight is arbitrary and merely supposed for illustrative purposes. The value of the fourth priority, i.e. 10, represents the failure of the solution to minimize the overachievement of row 1 (see the slack analysis) to zero.

The remainder of the appendix presents the FORTRAN program used in this study to calculate the goal program solutions.

```
0001          DIMENSION RVLX(10,125)
0002          DIMENSION D(60,125)
0003          DIMENSION VALX(10,125)
0004          DIMENSION C(60,125)
0005          DIMENSION VALY(60,10)
0006          DIMENSION KEPT(60)
0007          DIMENSION   RHS1(60)
0008          DIMENSION Y(60),IY(60)
0009          DIMENSION PRDT(60)
0010          DIMENSION AMT(60)
0011          DIMENSION  ZVAL(10)
0012          DIMENSION  DOD(60)
0013          DIMENSION  DUD(125)
0014          DIMENSION X(125)
        C     GOAL PROGRAMMING
0015          CALL START(N,M,L,C,VALX,VALY,PRDT,RHS1,KPCK,KEPT,TEST)
0016          DO 21 J=1,M
0017       21 X(J)=J
0018          DO 20 I=1,N
0019       20 Y(I)=I
0020       15 FORMAT(I3,F12.2)
0021       12 FORMAT(10F12.3)
0022      13  FORMAT(8F9.0)
0023      213 FORMAT(F8.0,10X,F15.5)
0024      313 FORMAT(I3,10X,F20.5)
0025          DO 25 K=1,L
0026          DO 25 I=1,N
0027          VALY(I,K)=VALX(K,I)
0028       25 CONTINUE
0029          ITAB=0
        C     BRING IN NEW VARIABLES
0030          ITER=0
        C     CALCULATE NET CONTRIBUTION OF EACH VARIABLE (RVLX(K,J))
0031       31 L1=0
0032       32 K3=L-L1
0033       33 IF(K3-1) 800,40,40
0034       40 DO 60 K=1,K3
0035          DO 60 J=1,M
0036          SUMP=0.
0037          DO 50 I=1,N
0038          P=VALY(I,K)*C(I,J)
0039          SUMP=SUMP+P
0040       50 CONTINUE
0041          RVLX(K,J)=SUMP-VALX(K,J)
0042       60 CONTINUE
        C     BRING IN X(K2)
0043          ZMAX=0.
0044          DO 90 J=1,M
0045          IF(K3-L) 92,70,70
0046       92 K4=K3+1
0047          DO 91 K=K4,L
0048          IF(RVLX(K,J)) 90,91,91
0049       91 CONTINUE
0050       70 IF(RVLX(K3,J)-ZMAX) 90,90,80
0051       80 ZMAX=RVLX(K3,J)
0052          K2=J
```

```
   90 CONTINUE
   95 IF(ZMAX) 790,790,100
C     WHICH VARIABLE IS REMOVED FROM THE BASIS
C     CALCULATE LIMITING AMT FOR EACH BASIS VARIABLE
  100 DO 150 I=1,N
      IF(PRDT(I)) 110,120,120
  110 WRITE(6,13) PRDT(I)
      GO TO 830
  120 IF(C(I,K2)) 130,130,140
  130 AMT(I)=-1.
      GO TO 150
  140 AMT(I)=PRDT(I)/C(I,K2)
  150 CONTINUE
C     SELECT SMALLEST POSITIVE LIMITING AMT
      I=1
  160 IF(AMT(I)) 170,210,210
  170 I=I+1
      IF(I-N) 160,160,180
  180 WRITE(6,13) AMT(N)
      GO TO 830
  210 ZMIN=AMT(I)
      K1=I
  220 I=I+1
      IF(I-N) 230,230,300
  230 IF(AMT(I)) 220,240,240
  240 IF(ZMIN-AMT(I)) 220,220,210
C     REMOVE Y(K1)
  300 Y(K1)=X(K2)
      DO 310 K=1,L
      VALY(K1,K)=VALX(K,K2)
  310 CONTINUE
C     CALCULATE NEW RIGHT-HAND SIDES
      DO 400 I=1,N
      PRDT(I)=PRDT(I)-ZMIN*C(I,K2)
  400 CONTINUE
      PRDT(K1)=ZMIN
C     CALCULATE NEW SUBSTITUTION RATES
      DO 500 J=1,M
      DO 500 I=1,N
      D(I,J)=C(I,J)-C(K1,J)* C(I,K2)/C(K1,K2)
  500 CONTINUE
      DO 510 J=1,M
      D(K1,J)=C(K1,J)/C(K1,K2)
  510 CONTINUE
      DO 520 J=1,M
      DO 520 I=1,N
      C(I,J)=D(I,J)
      IF(ABS(C(I,J)).LE.0.00001)C(I,J)=0.
  520 CONTINUE
      ITER=ITER+1
C     WRITE ALL TABLES OR JUST OPTIMAL TABLE
      IF(ITAB) 40,40,600
C     WRITE EACH TABLE
  600 WRITE(6,6001) ITER
 6001 FORMAT(1H1,10X,13HITERATIONS = ,I3,//)
      WRITE(6,5001)
```

```
                DO 610 I=1,N
                IY(I)=Y(I)
                WRITE(6,313) IY(I),PROT(I)
          610   CONTINUE
                WRITE(6,5002)
                DO 620 I=1,N
                WRITE(6,5006)I
                WRITE(6,12) (C(I,J),J=1,M)
          620   CONTINUE
                WRITE(6,5003)
         6813   DO 6814 K=1,L
                MM=L+1-K
                WRITE(6,5007) MM
                WRITE(6,12) (RVLX(K,J), J=1,M)
         6814    CONTINUE
                GO TO 40
C               MOVE TO NEXT LOWER PRIORITY LEVEL
          790   L1=L1+1
                GO TO 32
C               WRITE FINAL RESULTS
          800   WRITE(6,1015)
         1015   FORMAT(1H1)
                WRITE(6,1014)ITER
         1014   FORMAT(10X,'ITERATIONS.............',I5)
                WRITE(6,5000)
         5000   FORMAT(55X,'THE SIMPLEX SOLUTION',25X,'PAGE 05',//)
                WRITE(6,5001)
         5001   FORMAT(//,' THE RIGHT HAND SIDE',//)
          801   DO 810 I=1,N
                IY(I)=Y(I)
                WRITE(6,313) IY(I),PRDT(I)
          810   CONTINUE
                WRITE(6,5002)
         5002   FORMAT(//,' THE SUBSTITUTION RATES',//)
          811   DO 812 I=1,N
                WRITE(6,5006)I
         5006   FORMAT(1X,3HROW,I5)
                WRITE(6,12)(C(I,J),J=1,M)
          812   CONTINUE
                WRITE(6,5003)
         5003   FORMAT(//,' THE ZJ-CJ MATRIX',//)
          813   DO 814 K=1,L
                MM=L+1-K
                WRITE(6,5007) MM
         5007   FORMAT(1X,8HPRIORITY,I5)
                WRITE(6,12) (RVLX(K,J), J=1,M)
          814   CONTINUE
C               EVALUATE OBJECTIVE FUNCTION
                DO 820 K=1,L
                ZVAL(K)=0.
                DO 820 I=1,N
                ZVAL(K)=ZVAL(K)+PRDT(I)*VALY(I,K)
          820   CONTINUE
                WRITE(6,5004)
         5004   FORMAT( ' AN EVALUATION OF THE OBJECTIVE FUNCTION')
                DO 821 K=1,L
```

```
      KK=L-K
      IF(TEST.EQ.1.0)GO TO 89
      KK=KK+1
   89 WRITE(6,15) KK,ZVAL(K)
  821 CONTINUE
      CALL FINISH(RHS1,PRDT,VALY,L,KPCK,Y,N,KEPT,TEST)
  630 STOP
      END
```

```
      SUBROUTINE START(NROWS,NVAR,NPRT,C,VALX,VALY,RHS ,RHS1,KPCK,KEPT,T
     %EST)
C         THE START SUBROUTINE IS DESIGNED TO TAKE  INFORMATION IN A SPED-
C         IFIED FORMAT AND TRANSFORM IT INTO A SERIES OF USABLE MATRICIES.
C.....................................................................
      REAL NEG
      REAL L
      DIMENSION C(60,125),VALX(10,125)
      DIMENSION VALY(60,10)
      DIMENSION EQUALS(60),RVLX(10,125)
      DIMENSION RHS(60)
      DIMENSION KEPT(60)
      DIMENSION RHS1(60)
      NV=125
      NR=60
    1 FORMAT(A4,3I3)
      DATA POS,NEG/'POS ','NEG '/
      DATA DATA/'DATA'/
      DATA OBJ/'OBJ '/
      DATA PROB/'PROB'/
      DATA B /'B'/
      DATA E,G,L/'E','G','L'/
      DATA  RGHT/'RGHT'/
      TEST=0.0
C
C
C
C
C         READ THE  PROBLEM CARD  FOR THE NUMBER OF ROWS,VARIABLES, AND
C.....................................................................
   10 READ(5,1)ANAME,NROWS,NVAR,NPRT
      LISP=NPRT+1
      IF(NVAR.LE.0) GO TO 1020
      IF(NPRT.LE.0) GO TO 1020
      IF(NROWS.LE.0) GO TO 1020
      IF(ANAME.NE.PROB) GO TO 901
C
C
C         READ THE SIGN CARD.
C         IT WILL CONTAIN ONE OF THE FOLLOWING LETTERS FOR EACH ROW
C         FOR EQUALS                        E
C         FOR LESS THAN OR EQUAL TO         L
C         FOR GREATER THAN OR EQUAL TO      G
C         FOR BOTH DEVIATIONS               B
C.....................................................................
      READ(5,11)(EQUALS(I),I=1,NROWS)
   11 FORMAT(80A1)
C
C
      NAPT=0
C         COUNT THE NUMBER OF POSITIVE SLACK VARIABLES
C.....................................................................
      NFLDS=0
      DO 12 I=1,NROWS
      IF(EQUALS(I).EQ.B)NFLDS=NFLDS+1
   12 IF(EQUALS(I).EQ.G)NFLDS=NFLDS+1
```

```
      C
      C
      C          TEST FOR SIZE
      C.......................................................................
            NSIZE=NFLDS+NROWS+NVAR
            IF(NROWS.GT.NR) GO TO 911
            IF(NSIZE.GT.NV) GO TO 911
      C
      C
      C
      C          CLEAR ALL MATRICIES
      C.......................................................................
            IF (NPRT.GT.NROWS) GO TO 1105
            NUM = NROWS
            GO TO 1106
       1105 NUM = NPRT
       1106 KDUD = NPRT + 1
            DO 16 J=1,NSIZE
            DO 16 I = 1, NUM
            KEPT(I)=0
            IF(I.GT.KDUD) GO TO 17
            K=I
            RVLX(K,J)=0.0
            VALX(K,J)=0.0
         17 IF(I.EQ.J) C(I,J)=1.0
            VALY(I,K)=0.0
            IF(I.NE.J) C(I,J)=0.0
         16 CONTINUE
            KPCK=0
            K=KDUD
      C
      C
      C          ADJUST THE SLACK VARIABLES AND OBJECTIVE FUNCTION TO MEET THE
      C          REQUIREMENTS OF THE SIGN
      C.......................................................................
            DO 13 I=1,NROWS
            IF(EQUALS(I).EQ.E) GO TO 14
            IF(EQUALS(I).EQ.G) GO TO 15
            IF(EQUALS(I).EQ.L) GO TO 13
            IF(EQUALS(I).EQ.B)GO TO 18
            GO TO 910
         14 J=I
            VALX(K,J)=1.0
            NART=NART+1
            TEST=1.0
            GO TO 13
         15 KPCK=KPCK+1
            J=NROWS+KPCK
            C(I,J)=-1.0
            KEPT(I)=J
            J=I
            VALX(K,J)=1.
            NART=NART+1
            TEST=1.0
            GO TO 13
         18 KPCK=KPCK+1
```

```
      SUBROUTINE FINISH(RHS1,RHS,VALY,NPRT,KPCK,Y,NROWS,KEPT,TEST)
      REAL NEGSLK
      DIMENSION VALY(60,10)
      DIMENSION ZVAL(10)
      DIMENSION RHS(60)
      DIMENSION KEPT(60)
      DIMENSION Y(60),RHS1(60)
C        RHS1 IS THE RESERVED VECTOR OF RHS VALUES  FROM THE BEGINNING.
C        THE ENDING RHS VALUES ARE SUBTRACTED FROM THE BEGINNING ONES
C        AND THE RESULT IS PLACED INTO THE APPROPRIATE SLACK COLUMN.
C        THE REMAINDER OF THE VALUES  ARE PRINTED ON PAGE TWO OF THE RE-
C        SULTS.
C
C
C     SLACK ANALYSIS
C
      WRITE(6,21)
   21 FORMAT(1H1,120X,'PAGE  06'//,50X,'SLACK ANALYSIS')
    1 FORMAT(////)
      WRITE(6,1)
      WRITE(6,8)
    8 FORMAT(10X,'ROW',6X,'AVAILABLE',12X,'POS-SLK',12X'NEG-SLK')
      WRITE(6,1)
      DO 19 I=1,NROWS
      NEGSLK=0.0
      POSSLK=0.0
      DO 11 J=1,NROWS
      M=Y(J)
      IF(I-M) 9,10,9
    9 IF(M-KEPT(I))  11,12,11
   11 CONTINUE
      GO TO 13
   10 NEGSLK=RHS(J)
      GO TO 13
   12 POSSLK=RHS(J)
   13 WRITE(6,14)I,RHS1(I),POSSLK,NEGSLK
   14 FORMAT(10X,I3,3F20.5)
   19 CONTINUE
   43 FORMAT(10X,I3,3X,F15.5)
C
C     VARIBLE AMOUNTS
C
      WRITE(6,44)
   44 FORMAT(1H1,120X,'PAGE 07'//,50X,'VARIABLE ANALYSIS')
      WRITE(6,45)
   45 FORMAT(////,7X,'VARIABLE        AMOUNT',//)
      DO 41 I=1,NROWS
      NCHCK=Y(I)-KPCK-NROWS
      IF(NCHCK)41,41,42
   42 WRITE(6,43)NCHCK,RHS(I)
   41 CONTINUE
      WRITE(6,72)
   72 FORMAT(1H1)
      WRITE(6,50)
   50 FORMAT(//,55X,'ANALYSIS OF THE OBJECTIVE',23X,'PAGE 8',////,50X,'P
     &RIORITY',10X,'UNDER-ACHIEVEMENT',/)
```

```
      DO 52 K=1,NPRT
      ZVAL(K)=0.0
      DO 51 I=1,NROWS
   51 ZVAL(K)=ZVAL(K) +VALY(I,K)*RHS(I)
      LISP=NPRT+1
      KK=LISP-K
      IF(TEST.EQ.0.0) GO TO 52
      KK=NPRT-K
      IF(KK.GT.0) GO TO 52
      KK=NPRT-K
      IF(KK.GT.0) GO TO 52
      WRITE(6,78) ZVAL(K)
   78 FORMAT(/,45X,'ARTIFICIAL',5X,F20.5)
      GO TO 77
   52 WRITE(6,53) KK,ZVAL(K)
   53 FORMAT(1H0,52X,I2,5X,F20.5)
   77 CONTINUE
      STOP
      END
```

```
      J=KPCK+NROWS
      C(I,J)=-1.0
      KEPT(I)=J
   13 CONTINUE
C
C
C        READ THE OBJECTIVE FUNCTION
C.................................................................
      READ(5,21)ANAME
   19 I=0
      IF(ANAME.NE.OBJ) GO TO 920
      IF(ANAME.EQ.OBJ) GO TO 20
   20 READ(5,21)ANAME,I,M,TEMP
      IF(ANAME.EQ.DATA) GO TO 30
      IF(M.LE.0) GO TO 1022
      K=LISP-M
   21 FORMAT(A4,2I5,F16.0)
      IF(J.LE.0) GO TO 1022
      IF(K.GT.NPRT)  GO TO 1024
      IF(ANAME.EQ.NEG) GO TO 26
      IF(ANAME.EQ.POS) GO TO 25
      GO TO 27
   26 J=I
      VALX(K,J)=TEMP
      GO TO 20
   25 J=KEPT(I)
      IF (KEPT(I).EQ.0) GO TO 1026
      VALX(K,J)=TEMP
      GO TO 20
   27 IF(TEMP)926,20,926
C
C
C        READ THE DATA MATRIX IN
C.................................................................
   30 READ(5,21)ANAME,I,J,TEMP
      IF(ANAME.EQ.RGHT) GO TO 40
      IF(I.LE.0) GO TO 1090
      IF(J.EQ.0) GO TO 1090
      J=KPCK+NROWS+J
      C(I,J)=TEMP
      GO TO 30
C
C
C        READ THE RIGHT HAND SIDE
C.................................................................
   40 READ(5,44)(RHS(I),I=1,NROWS)
   44 FORMAT(8F10.0)
C
C
C        WRITE THE ABOVE RESULTS
C.................................................................
      WRITE(6,5015)
 5015 FORMAT(55X,'THE RIGHT HAND SIDE-INPUT',33X,'PAGE 01')
      DO 41 I=1,NROWS
      IF(RHS(I))941,42,43
   42 RHS(I)=.00001
```

```
0116          43  RHS1(I)=RHS(I)
0117              WRITE(6,1111)I,RHS(I)
0118        1111  FORMAT(10X,I3,2X,F15.5 )
0119          41  CONTINUE
0120              WRITE(6,620)
0121         620  FORMAT(1H1)
0122              WRITE(6,5016)
0123        5016  FORMAT(55X,'THE SUBSTITUTION RATES-INPUT',18X,'PAGE 02')
0124              DO 1112 I=1,NROWS
0125              WRITE(6,2519) I
0126        2519  FORMAT(1X,'ROW',I5)
0127        1112  WRITE(6,1113)(C(I,J),J=1,NSIZE)
0128        1113  FORMAT(10F12.3)
0129              WRITE(6,620)
0130              WRITE(6,5017)
0131        5017  FORMAT(55X,'THE OBJECTIVE FUNCTION-INPUT',19X,'PAGE 03')
0132              DO 1114 K=1,NPRT
0133              M=LISP-K
0134              WRITE(6,2150) M
0135        2150  FORMAT(' PRIORITY',I5)
0136        1114  WRITE(6,1113)(VALX(K,J),J=1,NSIZE)
0137              WRITE(6,620)
0138              WRITE(6,5018)
0139        5018  FORMAT(55X,'SUMMARY OF INPUT INFORMATION ',19X,'PAGE',' 04')
0140              NVAR=NSIZE
0141              WRITE(6,2017) NROWS,NVAR,NPRT,NART
0142        2017  FORMAT(10X,'NUMBER OF ROWS.........',I5,/,10X,'NUMBER OF VARIABLES
                 *....'    ,I5,/,10X,'NUMBER OF PRIORITIES...',I5,/,10X,'ADDED PRIOR
                 2ITIES.......',I5)
0143              IF(NART.GT.0)   NPRT=NPRT+1
0144              RETURN
0145         910  WRITE(6,914)
0146         914  0FORMAT('PROGRAM CONTAINS AN ERROR EITHER IN THE NUMBER OF ROWS PUN
                 1CHED OR IN THE SIGN CARD.THE VALUE IS SOMETHING OTHER THAN "E","G"
                 2,OR"L"')
0147              GO TO 999
0148        1090  WRITE(6,1091)
0149        1091  FORMAT('  IMPROPER DATA COLUMN OR ROW DEFINITION')
0150              GO TO 999
0151         920  WRITE(6,921)
0152         921  0FORMAT('  AN OBJECTIVE CARD WITH THE VALUE',F16.3,'             I
                 1S FOUND BUT INSTRUCTIONS AS TO WHICH DEVIATION HAS BEEN NEGLECTED.
                 2EXAMINE YOUR DATA ')
0153              GO TO 999
0154        1020  WRITE(6,1021)
0155        1021  FORMAT('  NUMBER OF ROWS, VARIABLES, OR PRIORITIES CANNOT BE EQUA
                 1L TO ZERO UNDER ANY CIRCUMSTANCES')
0156              GO TO 999
0157        1022  WRITE(6,1023)
0158        1023  FORMAT('  COLUMN VALUE OR PRIORITY VALUE IS EQUAL TO OR LESS THAN
                 1ZERO          ')
0159              GO TO 999
0160         911  WRITE(6,912)
0161         912  0FORMAT('  THE NUMBER OF VARIABLES NEEDED TO COMPUTE THIS PROGRAM
                 1IS TOO GREAT UNDER PRESENT DIMENSIONS.  SEE YOUR PROGRAMMER FOR AL
                 2TERING THIS RESTRICTION TO MEET YOUR NEEDS')
```

```
0162          GO TO 999
0163     1026 WRITE(6,1027)
0164     1027 FORMAT('  ATTEMPT IS MADE TO MINIMIZE NON EXISTANT POSITIVE  DEVIA
             1TION')
0165          GO TO 999
0166     1024 WRITE(6,1025)
0167     1025 FORMAT('  OBJECTIVE FUNCTION PRIORITY EXCEEDS STATED NUMBER OF PRI
             1ORITIES')
0168          GO TO 999
0169      901 WRITE(6,902)
0170      902 FORMAT(' PROBLEM CARD MISSING OR MISPUNCHED')
0171          GO TO 999
0172      926 WRITE(6,927)
0173      927 FORMAT('  A CARD IN THE OBJECTIVE SECTION DEFINED SOME VALUE FOR T
             1HE OBJECTIVE FUNCTION BUT FAILED TO DEFINE WHETHER THIS WAS TO AP
             2PLY TO THE POSITIVE OR NEGATIVE DEVIATION')
0174      941 WRITE(6,942)
0175      942 FORMAT('  NEGATIVE VALUES ARE NOT ALLOWED ON THE RIGHT HAND SIDE.
             1 CORRECT PROBLEM BY MULTIPLYING ENTIRE CONSTRAINT THROUGH BY MINU
             2S ONE.')
0176          GO TO 999
0177      999 STOP
0178          END
```